US ARMY CORPS OF ENGINEERS
NORTHWESTERN DIVISION
ANADROMOUS FISH EVALUATION PROGRAM

1998 ANNUAL PROGRAM REVIEW

OCTOBER 13-15, 1998
WORLD TRADE CENTER AUDITORIUM
2 WORLD TRADE CENTER
25 SW SALMON STREET
PORTLAND, OREGON

DAY 1 - TUESDAY, OCTOBER 13, 1998

8:00-8:30 Registration.
8:30-8:45 Opening Remarks. Witt Anderson, US Army Corps of Engineers, Northwestern Division

Surface Bypass
Moderator: Blaine Ebberts, US Army Corps of Engineers, Portland District

8:45-9:30 **Hydroacoustic Evaluation of Juvenile Salmon passage through Experimental Routes at Bonneville Dam.** Mr.Gene Ploskey, Waterways Experiment Station

9:30-10:00 **Movement, Distribution and Behavior of Radio-Tagged Juvenile Salmonids at the Bonneville Dam.** Mr. Rip Shively, US Geological Survey

10:00-10:20 **Dual-Head Multibeam Sonar: A New Technique for 3-D Fish Tracking.** Mr. Robert Johnson, Battelle, Pacific Northwest National Laboratory

10:20-10:35 **Fish Behavior in Front of the Prototype Surface Collector at Bonneville Dam.** Mr. Russell Moursund, Battelle Northwest

10:35-10:50 **Break**

Moderator: Tim Wik, US Army Corps of Engineers, Walla Walla District

10:50-11:20 **Migrational characteristics of Juvenile Spring and Fall Chinook Salmon and Steelhead in the Forebay of Lower Granite Dam Relative to the 1998 Surface Bypass and Collector Tests.** Mr. Noah Adams, US Geological Survey

11:20-11:50 **Forebay Mobile Telemetry Relative to 1998 SBC/BGS Test.** Mr. Michael Tuell and Mr. Scott Everett, Nez Perce Tribe of Idaho

11:50-12:20 **Fish Passage at the Prototype Surface Bypass Structures at Lower Granite Dam in Spring 1998.** Mr. Gary Johnson, Battelle, Pacific Northwest National Laboratory

12:20-1:20 **Lunch**

1:20-1:45 **Fish Behavior Evaluations in the Forebay of Lower Granite Dam.** Ms. Sue Blanton, Battelle, Pacific Northwest National Laboratory

1:45-2:00 **Distribution and Movements of the Northern Squawfish and Smallmouth Bass at Lower Granite Dam in Relation to the Operation of a Juvenile Salmonid Surface Bypass and Collection System.** Mr. Rich Piakowski, US Geological Survey, BRD, Idaho Cooperative Fish and Wildlife Research Unit

2:00-2:15 **Evaluation of Adult Chinook Salmon Passage at Lower Granite Dam During Testing and Operation of a Prototype Surface Bypass Collector.** Dr. Ted Bjornn, US Geological Survey, BRD, Idaho Cooperative Fish and Wildlife Research Unit

2:15-2:40 **Predator Abundance and Salmonid Prey Consumption in Lower Granite Reservoir and Tailrace.** Dr. David Bennett, Department of Fish and Wildlife, University of Idaho

2:40-2:55 **Break**

Adult Passage
Moderator: John Ferguson, US Army Corps of Engineers, Portland District

2:55-3:35 **Evaluation of Adult Salmon, Steelhead and Lamprey Migrations Past Dams and Through Reservoirs in the Lower Columbia River and into Tributaries.** Dr. Ted Bjornn and Mr. Lowell Stuehrenberg, US Geological Survey

3:35-4:05 **Radio Telemetry of Adult Pacific Lamprey (Lampetra tridentata) in the Lower Columbia River.** John Vella, National Marine Fisheries Service

4:05-4:35 **Upstream Migration of Pacific Lamprey (Lampetra tridentata) in The Columbia River.** Mr. James Seelye and Ms. Jennifer Bayer, U.S. Geological Survey

4:35-5:00 **Temperature Evaluations in the Lower Granite and Ice Harbor Fishway.** Dr. Ted Bjornn, US Geological Survey, BRD, Idaho Cooperative Fish and Wildlife Research Unit

DAY 2 - WEDNESDAY, OCTOBER 14, 1998

Spill Passage Evaluations
Moderator: Mr. Marvin Shutters, US Army Corps of Engineers, Portland District

8:00-8:30 **Relative Survival of Juvenile Salmon Passing Through the Spillway of The Dalles Dam, 1998.** Mr. Lyle Gilbreath, National Marine Fisheries Service

8:30-9:00 **Hydroacoustic Evaluation of Anadromous Fish Passage at The Dalles Dam.** Mr. Marvin Shutters, US Army Corps of Engineers, Portland District

9:00-9:30 **Movement, Distribution and Behavior of Radio-Tagged Juvenile Salmonids at the John Day Dam.** Mr. Rip Shively or Mr. Glen Holmberg, US Geological Survey

9:30-9:50 **Break**

9:50-10:20 **Hydroacoustic Evaluation of Anadromous Fish Passage at John Day Dam.** Mr. Marvin Shutters, US Army Corps of Engineers, Portland District

10:20-10:50 **Evaluation of the Effects of Spill Deflectors on Adult Salmon Passage at Ice Harbor Dam.** Dr. Ted Bjornn, US Geological Survey, BRD, Idaho Cooperative Fish and Wildlife Research Unit

Miscellaneous Studies
Moderator: John Ferguson, US Army Corps of Engineers, Portland District

10:50-11:20 **The Behavior of Juvenile Salmon Migrants during passage through a Kaplan Turbine (progress review).** Dr. Tom Carlson, Waterways Experiment Station

11:20-11:50 **The Effectiveness of strobe lights for Vertically Displacing Juvenile Salmon out of flow entering a 14 x 16 ft. filling intake at Hiram Chittenden Locks, Seattle.** Mr. Fred Goetz, US Army Corps of Engineers, Seattle District

11:50-1:00 **Lunch**

Gas Abatement
Moderator: Rock Peters, US Army Corps of Engineers, Portland District

1:00-1:30 **Two-Dimensional Hydrodynamic, Water Quality and Fish Exposure Modeling of the Columbia And Snake Rivers.** Dr. Marshall Richmond, Mr. William Perkins and Mr. Timothy Scheibe, Battelle Northwest

1:30-2:00 **Mechanical Injury with Emphasis on Effects From Spillways and Stilling Basins.** Mr. Michael Ramey and Mr. Ed Connor, R2 Resource Consultants, Inc.

2:00-2:15 **Break**

Bypass Systems/Collection Facilities
Moderator: Rebecca Kalamasz, US Army Corps of Engineers, Walla Walla District

2:15-2:45 **Evaluation of Extended-Length Bar Screens at Bonneville Dam First Powerhouse.** Mr. Bruce Monk, National Marine Fisheries Service

2:45-3:15 **Fish Guidance Efficiency of Extended-Length Bar Screens at Lower Granite Dam in Spring 1997 and 1998.** Mr. Steve Anglea, Mr. Gary Johnson, Mr. Eddie Kudera and Dr. John Skalski, Battelle, Pacific Northwest National Laboratory

3:15-3:45 **Evaluation of Orifice Shelters and Flow Control Devices at McNary Dam.** Mr. Mike Gessel, National Marine Fisheries Service

3:45-4:00 **Break**

4:00-4:30 **Post Construction Evaluation of the New Juvenile Bypass System at John Day Dam.** Mr. Randall Absolon, National Marine Fisheries Service

DAY 3- THURSDAY, OCTOBER 15, 1998

Mainstem Passage Evaluations - Transportation

Moderator: Rebecca Kalamasz, US Army Corps of Engineers, Walla Walla District

8:00-8:30 **Evaluation of Juvenile Salmonid Transportation.** Mr. Doug Marsh, National Marine Fisheries Service

8:30-9:00 **Estuarine Recovery of PIT-Tagged Juvenile Salmonids.** Mr. Richard Ledgerwood, National Marine Fisheries Service

9:00-9:30 **Evaluation of Migration and Survival of Juvenile Salmonids Following Transportation.** Dr. Carl Schreck and Mr. Tom Stahl, Oregon Cooperative Fish And Wildlife Research Unit, Oregon State University

9:30-10:00 **Caspian Tern Predation on Juvenile Salmonids in the Columbia River Estuary.** Mr. Dan Roby, Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University

10:00-10:15 **Break**

10:15-10:45 **Evaluation of Procedures for Collection, Transportation and Downstream Passage of Outmigrating Salmonids.** Dr. Jim Congleton, Dr. Diane Elliott and Mr. Ron Pascho, US Geological Survey

10:45-11:10 **Evaluation of the Effects of Multiple Dam Passage on The Physiological Condition of Migrating Juvenile Chinook Salmon.** Dr. Jim Congleton, US Geological Survey, BRD, Idaho Cooperative Fish and Wildlife Research Unit

11:10-11:40 **Evaluation of the Effects of Transportation on the Homing in Adult Chinook.** Dr. Ted Bjornn, US Geological Survey, BRD, Idaho Cooperative Fish and Wildlife Research Unit

11:40-12:10 **Improved Wet Separator Efficiency and High Velocity Flume Development.** Mr. Lynn McComas, National Marine Fisheries Service

12:10-12:30 **Improved Wet Separator Efficiency and Development of Methods for Secondary Separation of Large and Small Smolts.** Dr. Jim Congleton, US Geological Survey, BRD, Idaho Cooperative Fish and Wildlife Research Unit

12:30-1:30 **Lunch**

Lower Snake River Drawdown Feasibility

Moderator: Rick Jones, US Army Corps of Engineers, Walla Walla District

1:30-2:00 **Sport Fishing Use and Angling Characteristics on Snake River Reservoirs.** Mr. Chris Karchesky and Dr. David Bennett, Department of Fish and Wildlife, University of Idaho and Mr. Terry Euston, Normandeau Associates

2:00-2:25 **Use and Angling Characteristics of the Steelhead Sport Fishery on the Snake River Above Asotin, WA.** Mr. Chris Karchesky and Dr. David Bennett, Department of Fish and Wildlife, University of Idaho

2:25-2:55 **Predicting the Effects of Reservoir Drawdown on Juvenile Salmonids and their Predators.** Mr. James Petersen, US Geological Survey

2:55-3:15 **Identification of Fall Chinook Salmon Spawning Sites Near Lower Snake River Hydroelectric Projects.** Dr. Dennis Dauble, Battelle, Pacific Northwest National Laboratory.

3:15-3:30 **Break**

3:30-4:00 **Assessment of Drawdown from a Geomorphic Prospective Using GIS.** Mr. Duane Neitzel, Mr. Tim Hanrahan, Dr. Marshall Richmond, Battelle, Pacific Northwest National Laboratory.

4:00-4:30 **PIT-Tag Data Analysis and Review.** Dr. John Skalski, University of Washington.

4:30-4:45 **Snake River Drawdown Modeling in CRISP.** Dr. Jim Anderson, University of Washington Columbia River Research.

4:45 Annual Review Adjourned

HYDROACOUSTIC EVALUATION OF JUVENILE SALMON PASSAGE THROUGH EXPERIMENTAL ROUTES AT BONNEVILLE DAM

Gene Ploskey (USAE WES), Bill Nagy (CENWP-CO-SRF), Larry Lawrence (USAE WES), Deborah Patterson (Dyntel Inc.), Carl Schilt (AScI Inc.), Peter Johnson (AScI Inc.), John Skalski (Univ. of Wa), and Gina George, Athena Stillinger, and Jason King (Contract Students)

We used fixed-aspect hydroacoustics to evaluate the passage of juvenile salmon and the efficiency and effectiveness of several experimental passage routes at Bonneville Dam. Routes included a Prototype Surface Collector (PSC), units adjacent to the PSC with submerged traveling screens, Intake 8b with an extended length bar screen (ESBS), the sluice chute at Powerhouse 2, and units 11-13 adjacent to the sluice chute. We tested to see if 5- and 20-ft slot-width treatments altered fish-passage indices for the PSC. The width of the 40-ft-deep slots was changed every 2-days according to a random stratified design in spring and summer. We also tested effects of opened and closed sluice-chute treatments on fish-passage metrics for Powerhouse 2.

<u>Prototype Surface Collector</u>:

Hydroacoustic evaluations clearly indicate that the PSC tested in 1998 was exceptionally effective in collecting juvenile salmon.

The efficiency of the PSC was estimated in two ways. First, numbers of fish entering PSC slots were divided by the sum of numbers entering slots and numbers passing under the collector. Second, in-turbine counts of fish that passed through the collector were divided by the sum of numbers that passed through and numbers that passed under the PSC. The more conservative estimate of efficiency based upon in-turbine counts was consistently high in spring [90.0 $\pm$ 1.0 % (where the error term is a 95% confidence interval)] and summer (91 $\pm$ 1.1 %). This efficiency did not differ significantly between 5- and 20-ft slot treatments. Passage effectiveness, which describes the proportion of fish entering the collector relative to the proportion of water entering it, was significantly higher for the 5-ft slot than for the 20-ft slot. For the 5-ft slot, we found 9.5 and 7.5 times more fish were passed than would be expected from flow proportions at the PSC in spring and summer, respectively. For the 20-ft slot, only 3.1 times more fish passed into the PSC than would be expected from the proportion of flow entering the collector. Efficiency and effectiveness estimates were based upon over 100,000 fish passing through the PSC each season.

The mean number of fish entering collector slots was about 62 % of the number entering adjacent units and the PSC in spring and 50 % in summer. However, the opening at units 1 and 2 is about 3.2 times wider than the two 20-ft slot openings in the PSC and 12.6 times wider than the two 5-ft slot openings. Per ft^2 of opening width, the fraction of fish entering the PSC, relative to the total, was 0.89 in spring and 0.83 in summer. An obvious difference between the two types of openings is that the PSC is open to the sky and turbine intakes are not open. Units 1 and 2 also are adjacent to the old navigation lock wall that likely guides fish to those units. Unlike efficiencies of in-turbine screens, which typically decline from spring through summer, the efficiency of the PSC remained high throughout both seasons.

Extended Length Bar Screen:

The efficiency of the ESBS averaged 79.4 ± 3.6 % in spring and 56.9 ± 4 % in summer. It declined to about 40 % by the end of summer. The decline in efficiency from spring through summer was significant and was detected by both hydroacoustics and netting, although the decline indicated by net sampling was more pronounced. Daily netting estimates of efficiency were correlated with hydroacoustic estimates ($r^2 = 0.35$; $P < 0.0001$; $N = 41$). The poor fit of the correlation likely results from often-limited spatial coverage of the intake by fyke nets and limited spatial and temporal coverage of hydroacoustic samples. Hydroacoustic beams sampled only about 1/5th of the intake width at any instant in time, while fyke-nets usually covered one half of the intake width (Bruce Monk, NMFS, Personal Communication). Hydroacoustic effort was split between units 1, 2, and 8, and therefore Intake 8b was sampled only 15 minutes per hour, 23 hours per day. Netting was continuous from about 2000 until enough fish were captured to obtain some desired level of precision. Better correlations between hydroacoustic and netting samples can be obtained, but only with increased sampling, particularly for hydroacoustics. Decreasing numbers of guided fish and increasing numbers of unguided fish from spring through summer were detected by both methods. Hydroacoustic sampling showed much higher passage at night, particularly during the hour just after sunset, than during the day. However, no significant diel trend was apparent in hydroacoustic estimates of FGE.

Sluice Chute:

Hydroacoustic evaluations of fish passage at the Powerhouse 2 sluice chute and units 11-13 provided conclusive evidence that the sluice chute has great potential as a corner surface collector.

Turbine intake extensions on the south end of Powerhouse 2 were removed in 1998. Consequently, relatively laminar bulk flows moved along the powerhouse toward the sluice chute and water entering the sluice chute was less turbulent than in prior years. It provided a relatively noise-free environment for hydroacoustic sampling with three up-looking split-beam transducers. A pulse repetition rate of 37 pings per second provided uniform and adequate detectability despite high water velocities and short sampling ranges.

In spring, the mean combined efficiency of the sluice chute and submerged traveling screens in units 11-13 increased from 60 ± 4.5 % under closed-sluice treatments to 91 ± 1.4 % under opened-sluice treatments. In summer, mean combined efficiency increased from 38.5 ± 5.9 % during closed-sluice treatments to 92 ± 2.0 % during opened-sluice treatments. While the mean FGE of submerged traveling screens in units 11-13 decreased from spring through summer, combined efficiency of the sluice chute and traveling screens did not decline during summer. The efficiency of the sluice chute relative to total fish passage at the chute and units 11-13 was 83.0 ± 5.6 % in spring and 84.4 ± 8.3 % in summer. In spring, the average FGE of traveling screens in units 11-13 was 60.1 ± 4.6 %

when the sluice chute was closed and 48.4 % ± 6.6 % when the chute was opened. In summer, mean FGE of the traveling screens was 38.5 ± 5.9 % when the sluice chute was closed and 48.9 % ± 10.5 % when the chute was opened. The sluice chute passed 163,000 more fish than all nine intakes at units 11-13 over both seasons, despite having an opening that was < 1.1 % of the cross sectional area of openings to units 11-13. Estimates of effectiveness indicated that about five times more fish were passed by the sluice chute than would be expected from the proportion of water passing through the chute relative to the total for the chute and units 11-13. Effectiveness was 5.3 ± 0.36 in spring and 4.9 ± 0.48 in summer. Like combined efficiency, effectiveness did not decrease significantly during summer. The number of fish passing through units 11-13 was lower when the sluice chute was opened than when it was closed in spring but not in summer.

MOVEMENT, DISTRIBUTION, AND PASSAGE BEHAVIOR OF RADIO-TAGGED JUVENILE SALMONIDS AT BONNEVILLE DAM ASSOCIATED WITH THE SURFACE BYPASS PROGRAM, 1998

Rip S. Shively, Hal C. Hansel, Jay E. Hensleigh, and Thomas P. Poe. U.S. Geological Survey,
Biological Resources Division, Columbia River Research Laboratory, Cook, WA 98605.

In 1998, we used radio telemetry to examine the movements and behavior of yearling and subyearling chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) in the forebay of Bonneville Dam. In particular, we monitored fish behavior associated with tests of the prototype surface bypass collector (PSC) at Powerhouse I and operation of the sluice chute at Powerhouse II.

During the spring outmigration we released a total of 743 yearling chinook salmon and steelhead from the site specific release site 10 km above Bonneville Dam. In addition, 540 yearling chinook salmon and steelhead were released from John Day and McNary dams. We contacted approximately 96% of the fish released in the Bonneville Pool and 64% of the fish released from John Day and McNary dams. Of the 1,050 fish detected at Bonneville Dam, 32% were contacted at Powerhouse I, 26% were contacted at Powerhouse II, and 42% were contacted at the spillway. About 43% (79/182) of the juvenile steelhead and 40% (55/158) of yearling chinook salmon detected at Powerhouse I were contacted within 10 m of the PSC face. However, most fish (67%) contacting the PSC did not enter either units 3 or 5, but instead moved south along the PSC face. These fish usually held near turbine units 1 and 2, and either passed the dam there, or moved upriver and recontacted the dam at a later time. Overall, the percentage of fish entering the PSC was higher for entrance widths of 20' than 5'. With 5' wide entrance openings, about 23% (14/60) of the fish contacting the entrances entered the PSC, while with 20' wide entrances about 53% (30/57) of the fish entered the PSC. Overall, radio-tagged fish were also less likely to pass underneath the collector when entrance widths were 20'. Slot efficiencies (number entering PSC/ number entering PSC + number passing under the PSC) for 20' openings were 85% (17/20) for steelhead and 93% (13/14) for yearling chinook salmon, while for 5' openings slot efficiencies ranged between 100% (9/9) for steelhead and 42% (5/12) for yearling chinook salmon.

At Powerhouse II, 52% (42/81) of the steelhead and 36% (25/70) of the yearling chinook salmon that passed, exited through the sluice chute when it was open. An additional 21% (17/81) of the steelhead and 14% (10/70) of the chinook salmon were detected in the juvenile bypass channel when the sluice chute was open. When the sluice chute was closed, 50% (25/50) of the steelhead and 30% (20/66) of the chinook salmon were detected in the juvenile bypass channel.

During the summer outmigration we released a total of 482 subyearling chinook in the Bonneville Pool. An additional 271 subyearling chinook were released at John Day and McNary dams, but due to a limited number of receivers we did not specifically monitor for these fish. We contacted approximately 85.6% (413/482) of the fish released in Bonneville

Pool. Of the 413 subyearling chinook salmon detected at Bonneville Dam, 24% were contacted at Powerhouse I, 24% were contacted at Powerhouse II, and 52% were contacted at the spillway. About 55% (54/98) of the subyearling chinook salmon detected at Powerhouse I were contacted within 10 m of the PSC face. Of these fish, only 22% (12/54) were detected passing through the PSC. Most fish traveled south along the face of the PSC and held near turbine units 1 and 2 similar to spring migrants. Radio-tagged subyearling chinook salmon more readily entered the collector when entrance widths were 20' than 5'. With 20' openings, 50% (11/22) of the fish detected within 10 m of the entrances passed through the collector, while only 3% (1/32) entered when entrance widths were 5'. However, regardless of entrance width only one subyearling chinook salmon was detected passing under the PSC. Operation of the sluice chute at Powerhouse II was suspended shortly after we began releasing fish, therefore we have limited data for these tests.

In summary, while our data indicate that most fish (85-100%) entering units 3 and 5 passed through the PSC rather than under it when entrance widths were 20'. Also, approximately 50% of the fish within 10 m of a collector entrance passed through the collector when entrance widths were 20'. Both slot and entrance efficiencies were generally reduced when PSC entrance widths were 5'. We believe extrapolation of these entrance and slot efficiencies for a full-scale PSC must be done with caution since only a limited prototype was tested in 1998. Tests of opening and closing the sluice chute at Powerhouse II indicate that a high percentage of fish passing through the powerhouse use this route when it is open. In addition, fish passage efficiency is increased for Powerhouse II when the sluice chute is open.

DUAL-HEAD MULTIBEAM SONAR: A NEW TECHNIQUE FOR 3-D FISH TRACKING

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In 1997 we initiated a feasibility study in cooperation with the Walla Walla District Corps of Engineers to determine the applicability of a new technique for fine-scale fish behavior evaluations in support of prototype bypass structure testing. This new technique involved adapting multibeam sonar technology commonly used for hydrographic surveys and military applications to fisheries investigations. Thus, the Dual-Head Multibeam (DHM) technique was spawned to provide greater sample volume, 3-D fish tracking, and long fish track histories with a non-intrusive sampling tool. In other words, we have moved the focus of the sonar away from the bottom and into the water column.

The DHM technology has resulted in new insights, and questions, about the behavior of salmonid smolts as they approach prototype structures under test at Lower Granite and Bonneville Dams in 1998. The underlying operative hypothesis in these environments has been that smolts follow flow. We believe that this is true of the bulk flow regime. However, our results at two hydropower dams in 1998 demonstrated that this hypothesis is not necessarily true in the immediate forebay region of the prototype surface collection structures currently under test. Fish behavior within 30 m of those structures is very complex as is their environment, with many eddies, vortices, and sources of potentially behavior altering stimuli such as sound, light, and structure. The DHM technique deployed in 1998 has permitted us to "see" fine-scale fish behavior of large numbers of tracked targets without the need to conduct tagging experiments or otherwise disturb the migration of the target fish population. In numerous instances, smolts were observed moving across presumed flow lines, swimming upstream, or exhibiting positive rheotaxis far from the influence of the flow field designed to attract them.

The primary conclusion afforded by the DHM technique is that smolts approaching near a large hydropower facility exhibit very complex fine-scale behavior -- they are *not* particles going with the flow. Thus, a prototype surface collection device may be more or less effective, depending on its placement and configuration, because of a smolts' complex behavior. For instance, milling behavior may prove advantageous to safe passage if it results in an increased likelihood of smolts encountering an opening in the surface collector. Additional fine-scale behavior data will be needed to reinforce this conclusion. However, additional fine-scale fish track information is only part of the challenge. Continued development of the surface bypass concept and implementation of permanent structures will require better understanding of the mechanisms driving the behavior of migratory smolts near large hydropower dams. This better understanding will lead to better structural design. The following recommendations will help to address this need:

1. Large-scale laboratory experiments should be devised to better understand the stimuli that cause complex smolt behavior near these structures, i.e. what sensory mechanisms drive or cause their complex behavior?

2. Future studies should include baseline fine-scale behavior of smolts upstream of the influence of the hydropower facilities under test to answer the question: Do smolts behave differently before they encounter the dam? Or, is their fine-scale behavioral complexity normal during the migratory trek?

3. Fine-scale smolt behavior monitoring, in the near-structure forebay of test facilities, should be supplemented with monitoring of the complete environmental conditions that may affect the migrating smolts, including: light conditions, on-site fine-scale flow measurements, acoustic noise conditions, water conditions, etc. This information is critical to a successful field scale experiment.

The Dual-Head Multibeam approach was used to determine the fine-scale behavior of smolts approaching Lower Granite and Bonneville Dams in 1998. The approach was developed as a result of the need to track individual smolts for a long duration in a large volume of water with relatively fine-scale resolution. The Corps' vision in supporting this technology application, has placed them in a leading role in providing state-of-the-art technological solutions to critical and complex problems. This has been reinforced by a 1998 International Council for Exploration of the Seas (ICES) study group report on echo trace classification. In examining the future fisheries acoustics research tool, they concluded: "*One may imagine the ideal future acoustic tool for fish stock research: it would have a multibeam architecture …*". A 12-minute video presentation will explain the Dual-Head Multibeam technique from data collection to interactive computer visualization of smolt behavior. Subsequent presentations on fish behavior results at Bonneville and Lower Granite Dams will further elucidate our findings in 1998.

FISH BEHAVIOR IN FRONT OF THE PROTOTYPE SURFACE COLLECTOR AT BONNEVILLE DAM

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The prototype surface collector (PSC) at Powerhouse I of Bonneville Dam was evaluated in spring and summer of 1998. The PSC is a temporary structure designed to test surface bypass concepts. It spans Turbine Units 3-6, extends 6 m upstream into the forebay, and is 15 m high. For 1998, openings at the B Intakes of Units 3 and 5 were tested. Water entering the openings passed into the turbine units. Two vertical slot configurations were tested. The slot was either 1.5 m or 6 m wide, with both slots extending approximately 13.5 into the water column.

To perform the surface bypass studies at Bonneville Dam in 1998, the Pacific Northwest National Laboratory (PNNL) has been working in conjunction with the U.S. Corps of Engineers Waterways Experiment Station (WES). This study should be considered complementary to the WES study, "Hydroacoustic evaluation of juvenile salmon passage through experimental routes at Bonneville Dam".

The Dual Head Multibeam (DHM) hydroacoustic system used to collect behavior data was deployed from a floating platform moored in the forebay of Powerhouse I at Bonneville Dam. This platform was situated approximately 18.5 m from the face of the PSC, in front of Intake B at Unit 3. The transducers were mounted near the end of a 6 m (3.5 m submerged) pole. The vertical aiming angle was controlled remotely via a motor driven actuator arm. At the fixed deployment range, both horizontal and vertical coverage is approximately 10 m at the face of the PSC. The system collected data 24 hours/day from 0.2 m in front of the transducers (blanking range) up to the PSC opening. The data collection system included highly accurate positioning information from a laser radar system, GPS time, and barge compass heading, pitch, and roll sensors. All of these sensors collected data continuously. To facilitate data post-processing, the barge position, time, barge orientation, and echo information were all fused into a single data structure on a ping-to-ping basis.

The Bonneville DHM data set consists of 15,878 fish tracks with an associated 207,528 multidimensional records. Our results showed few differences between the 1.5 m and 6 m slot configurations. Depth and velocity distributions, track characteristics, and trajectories all varied the same regardless of configuration. However our analysis did show a number of general trends with range that offer more insight into fish behavior in front of this structure. As a population, fish traveled in all directions within the sample volume. Fish exhibited both holding and active swimming behaviors at all ranges. It is also clear that smolts at this location did not consistently exhibit positive rheotaxis or follow simple flow lines. Further, fish were not inevitably entrained nor did they actively swim away from or toward the slot for either configuration. This includes fish traveling parallel to the dam at all ranges, including very close to the slot opening.

While fish did exhibit specific behaviors, as a population a more appropriate model may be one that incorporates random walk features. Our results to date suggest that smolts were not only able to move freely through the forebay close to the structure, but did so readily. It is possible that the PSC, in it's current configuration, created a zone of holding (or perhaps a zone of free-swimming) that increased the opportunity for discovery of the entrances. For future design considerations, both the opportunity for discovery and entrance conditions deserve further investigation.

Flow information was not available at the time of this submission. Flow fields may shed additional light on smolt behavior once incorporated into the analysis.

MIGRATIONAL CHARACTERISTICS OF JUVENILE CHINOOK SALMON AND STEELHEAD IN THE FOREBAY OF LOWER GRANITE DAM RELATIVE TO THE 1998 SURFACE BYPASS COLLECTOR TESTS.

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Reservoir drawdown, flow augmentation, spill, and surface collection have been identified as potential management actions to improve the survival of migratory juvenile salmonids, thereby assisting the recovery of endangered salmon stocks in the Snake River. As part of this process the U.S. Army Corps of Engineers together with, regional, state, and federal resource agencies installed a prototype surface bypass collector (SBC) at Lower Granite Dam, Snake River, Washington in 1996. Based on results of tests conducted in spring of 1996 and spring/summer 1997, three major additions to the SBC were made for testing in 1998: 1) a Simulated Wells Intake (SWI), 2) a Behavioral Guidance Structure (BGS), and 3) a new overflow entrance on the SBC.

We used biotelemetry and mobile hydroacoustic/ADCP techniques to evaluate the effectiveness of the BGS, SWI, and SBC in attracting and passing juvenile spring and fall chinook salmon and steelhead during the spring and summer of 1998. In the spring, we tagged and released 399 juvenile spring chinook salmon, 214 hatchery steelhead, and 182 wild steelhead. During the summer study, a total of 295 juvenile fall chinook salmon were implanted with radio transmitters and released in Lower Granite Reservoir.

Our results indicated that the SBC, with the addition of the BGS and SWI, was much more effective at passing juvenile salmonids in 1998 than in 1997. Of the radio-tagged fish that passed LGD, 14% (49 of 361) of spring chinook salmon, 34% of fall chinook salmon (81 of 240), 32% (67 of 208) of hatchery steelhead and 15% (27 of 180) of wild steelhead passed the dam via the SBC. These efficiencies for SBC passage were more than double those seen in 1997 for spring chinook salmon (7%), fall chinook salmon (16%), hatchery steelhead (11%), and wild steelhead (9%).

The number of fish that came within 10 m of the SBC increased during 1998 compared to 1997. Forty-four percent (162 of 366) of spring chinook salmon, 65% of fall chinook salmon (166 of 261), 62% (131 of 213) of hatchery steelhead, and 43% (78 of 180) of wild steelhead came within 10 m of the openings to the SBC. In general these numbers were much higher than what we observed in 1997 (19%, spring chinook salmon; 63%, fall chinook salmon; 29%, hatchery steelhead; 31%, wild steelhead). Of the fish that came within 10 m of the openings to the SBC, 30% (n = 49) of spring chinook salmon, 45% (n = 75) of fall chinook salmon, 51% (n = 67) of hatchery steelhead and 35% (n = 27) of wild steelhead passed into and through the SBC. These numbers were not substantially different than what we observed in 1997.

Our results indicated that the BGS was effective at diverting fish away from turbines 1,2, and 3. We used two measures to estimate the effectiveness of the BGS. BGS diversion probability was based on the proportion of fish (of total passage through all routes at the dam) entering turbines 1-3 with the BGS in vs. out. This estimate indicated that the BGS diverted 69% of spring chinook salmon, 86% of hatchery steelhead, and 65% of wild steelhead away from turbines 1-3. Because the BGS was in during the entire summer study period, there was no estimate of diversion probability for fall chinook salmon. The second measure of BGS effectiveness, BGS guidance efficiency, was based on the proportion of fish passing under the BGS of those that came within 30 m of the BGS. Using this measure, the BGS guided 61% of spring chinook salmon, 78% of fall chinook salmon, 92% of hatchery steelhead, and 67% of wild steelhead away from turbines 1-3. The presence of the BGS did not substantially increase residence times in the forebay. Median forebay residence times for all fish when the BGS was "in" during 100% of their time in the forebay (0.6 - 1.5 hours) was shorter than median times for fish when the BGS was "out" for 100% of their time in the forebay (1.7 - 3.6 hours).

Mobile hydroacoustic data indicated that the majority of outmigrating juvenile salmonids were distributed above the bottom of the BGS, thereby making them "guidable" by the BGS. Fish movement vectors at sampling sites about 100 m from the north face of the BGS showed a higher percentage of downstream movement than what was observed at sampling sites immediately in front of the BGS. Downward movement in the water column accounted for the highest percentage of vertical fish movement. Downward fish movement increased along the BGS as distance from the face of the SBC decreased. Water velocity vectors showed a similar pattern.

In summary, the addition of the BGS and SWI appeared to accomplish the desired results: more fish were diverted into the area immediately upstream of the SBC in 1998 compared to 1997. However, we did not observe the same relative increase in the proportion of fish entering the SBC of those within 10 m of the openings. More research is needed to determine why more of the "available" fish did not enter the SBC. A potential explanation is that the flow net created by the relatively small amount of water passing through the SBC (about 3% of total flow at the dam) was not sufficient enough, or of the desired type (laminar vs. turbulent flow), to encourage fish to enter.

FOREBAY MOBILE TELEMETRY RELATIVE TO 1998 SURFACE BYPASS COLLECTOR/BEHAVIORAL GUIDANCE STRUCTURE TEST AT LOWER GRANITE DAM

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Mobile radio-telemetry was used to locate individual juvenile salmonids in the forebay of Lower Granite Dam. Approach paths to Lower Granite Dam were determined for 46 juvenile spring chinook salmon, 66 hatchery steelhead, and 42 wild steelhead during the spring (10 April to 30 May), and 39 fall chinook salmon during the summer (1 July to13 July). Approach paths appear to congregate in front of the spillbays and the area of the SBC during the spring, and in front of the area of the SBC during the summer. Based on the 1998 tracking data, the current location of the SBC allows adequate opportunity for fish to detect it. No clear relationship was identified between approach paths and BGS location, dam passage routes for individual fish, and water velocity at fish locations. However, increased project discharge may influence the shape of approach paths. Spring and fall chinook salmon paths appear to approach the dam more directly with increased discharge. This relationship was not found in hatchery steelhead or wild steelhead.

FISH PASSAGE AT THE PROTOTYPE SURFACE BYPASS AND COLLECTOR AT LOWER GRANITE DAM IN SPRING 1996-1998

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Introduction

We collected fixed-location hydroacoustic data in spring 1996-1998 as part of a comprehensive evaluation of the prototype surface bypass and collector (SBC) at Lower Granite Dam on the Snake River. The goal of this evaluation was to provide information for the Lower Snake River Juvenile Salmon Migration Feasibility Study, which is due in 1999. In 1998, two major structures were added to the SBC originally installed in 1996 at Lower Granite Dam, a Simulated Wells Intake (SWI) and a Behavioral Guidance Structure (BGS). The general objectives of the fish passage work at the SBC in 1996-98 were to (1) Measure performance of the SBC and associated structures, and (2) Determine fish passage budgets for the SBC.

SBC Performance

SBC efficiency was higher in 1998 than 1996-1997 (Table 1). This may be attributed to the addition of the SWI on the bottom of the SWI. The SWI decreased the downward component of velocity in the forebay of the SBC, presumably reducing fish entrainment into the turbines below and increasing fish availability to the SBC.

Efficiency for a two-unit SBC (R_{4-5}) was 62% for the preferred configuration ("Ice Harbor" with horizontal surface entrances). This is the "stand-alone" performance for the SBC. The SBC in conjunction with extended-length intake screens, the "hybrid" approach, had an efficiency of 91%.

Table 1. SBC efficiency relative to the entire project (R_{all}), the powerhouse (R_{1-6}), Turbines 4-6 (R_{4-6}), and Turbines 4 and 5 (R_{4-5}). Confidence intervals are at 95% level.

Efficiency	1996	1997	1998
R_{all}	n/a	0.136 ± 0.003	0.268 ± 0.002
R_{1-6}	0.349 ± 0.003	0.293 ± 0.006	0.381 ± 0.003
R_{4-6}	0.427 ± 0.003	0.379 ± 0.010	0.510 ± 0.004
R_{4-5}	0.505 ± 0.004	0.462 ± 0.012	0.595 ± 0.005
N	0.61 to 0.69	0.65 to 0.75	0.56 to 0.59

Entrance efficiency (N) was lower in 1998 than 1996-1997 (Table 1). Lower overall efficiency was not due to the presence of the BGS as entrance efficiencies were similar whether the BGS was in or out. Reduced entrance efficiency occurred at the BGS and South entrances to the SBC, not the Middle and North entrances. Apparently entrance conditions, possibly related to relatively low velocities, were unsatisfactory at the south end of the BGS.

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BGS Performance

The BGS diverted 77.8% ± 18.0% of the fish intended for Turbines 1-3 to the north. Mean daily passage rates and proportions were generally lower at Turbines 1-3 and higher at Turbines 4-6, the SBC, and the spillway with the BGS in rather than out. The BGS apparently influenced fish migration through much of the forebay. While the BGS successfully diverted fish, some diverted fish did not enter the SBC, as demonstrated by higher SBC efficiency ($R_{4\text{-}6}$) with the BGS in than out. These data indicated that entrance conditions at the SBC might have been less than optimal. On the other hand, with the BGS in, enhanced passage at the spillway improved FPE such that there was a significant ($P = 0.026$) difference in FPE between BGS in and out conditions.

Fish Budgets

The fish budgets for 1996-1998 show that the 1998 prototype surface bypass structures increased the percentage of fish available to the SBC, i.e., within 3m of the entrances. This is because in 1998 more fish were above the bottom of the SBC (because of the SWI) and fewer fish were entrained than in previous years. This caused SBC efficiencies to increase in 1998. But, although the percentage of fish available to the SBC increased in 1998, the decrease in entrance efficiency meant that the percentage of fish near the SBC that ended up going through the turbines increased.

Recommendations

1. Improve entrance conditions by closing the BGS and South entrances and concentrating SBC discharge in the Middle and North entrances. Open these entrances from the surface to a depth where mean entrance velocities are about 3-4 fps.

2. Increase the percentage of SBC discharge out of total SBC and turbine discharge by running the turbines below the SBC at low load. Keep SBC discharge at its maximum 4,000 cfs.

3. Test the BGS with Turbines 1-3 at full load (~60 kcfs). In general, the BGS concept seems valid, although the first-year test in 1998 is not sufficient for long-term decision-making because Turbine 2 was off-line the entire study.

4. Test the prototype under low flow conditions. The prototype surface bypass structures have been tested under high flow conditions in 1996 (123% of normal) and 1997 (154% of normal) and average flow conditions in 1998 (101% of normal). Low flow periods are a most critical time for fish passage, and a time when a surface bypass might be expected to be most useful.

FISH BEHAVIOR EVALUATIONS IN THE FOREBAY OF LOWER GRANITE DAM

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Observations of fine-scale fish behavior in the presence of the latest system alterations at Lower Granite Dam contribute to the body of information concerning the benefits of such alterations to migrating juvenile salmonids. This year a new technology was used to provide information on fish movement patterns upstream of Lower Granite Dam to help explain the performance of the Surface Bypass and Collector (SBC), Simulated Wells Intake (SWI), and Behavioral Guidance Structure (BGS). A Dual-Head Multibeam (DHM) sonar system was deployed in the forebay of Lower Granite Dam during April and May 1998. It tracked juvenile salmonids in three dimensions as they approached the dam and the associated structures. This allowed us to classify the behavior of fish targets in particular regions of the forebay and allowed us to describe, in part, how fast fish were traveling, what direction they were moving, and where fish were milling. Because the BGS was moved in and out of position over the course of the study, differences in fish behavior in the presence and absence of the structure were ascertained. Other parameters possibly affecting fish behavior, such as seasonal and day/night influences, were also evaluated.

The behavior evaluations were conducted using two synchronized multibeam sonar systems. The DHM sonar heads were deployed from a small barge anchored in the Lower Granite forebay approximately 50 meters upstream of the middle entrance of the SBC. The sonar systems were fitted to a pipe below the water surface so they could be rotated through 140 degrees. This allowed sampling of a volume that extended from approximately 30 meters upstream of the north end of the SBC to the upstream end of the first BGS module and to depths ranging from 5 to 30 meters. Fish behavior could not, however, be determined with accuracy within approximately 6 meters of the SBC. The acoustic range of the DHM was limited because of backscattered acoustic noise from numerous floats, cables, and underwater radio antennae near the SBC and BGS structures. In all, the effective volume coverage of the DHM was approximately 40,500 m^3.

DHM data were collected from the two synchronized sonar heads and integrated with barge position, heading and tilt sensor data, and Universal Coordinated Time (UTC) from a Global Positioning System (GPS). Processing of tracked target data was accomplished using software developed by Battelle (MTrack v.2.3). During the process, targets were manually selected from noise by technicians. Exact positions and instantaneous velocities and accelerations were calculated for each target before the data were organized under various configuration scenarios and analyzed using visual and statistical techniques that were also developed by Battelle.

Several methods of analyses were applied to the data to generate graphical representations. These included evaluations of average target speed, tortuosity (total distance over straight-line distance), ellipsoidal volume (maximum range in each direction encompassed in an ellipse), and ellipsoid maximum axis. Through these graphics and a visualization software package that allowed a person to observe the movement of targets from an actual data set through the forebay, it was evident that fish moved in all directions within the forebay and did not simply follow the flow into the SBC or turbine entrances. However, it was possible to make some general observations about fish behavior in relation to the dam.

Results indicated that fish behavior in the Lower Granite Dam forebay was very complex. While it is generally believed that smolts follow water flow, the DHM results indicated that fish often moved across flow lines as they approached the dam and prototype surface collection structures. These results were apparent even though hydraulic data were not yet included in the evaluation. The addition of flow data will eventually allow us to exclude the effects of flow on fish displacement and allow us to determine where and when fish moved with and against the current. This will be important for relating changes in flow or proximity to structures to behavioral responses of the fish.

Overall, as expected, average fish speed increased as fish approached the dam. When the BGS was IN, fish speed was more highly erratic near the dam but slower overall than when the BGS was OUT. Milling behavior was more common near the dam and other structures than at a distance. Milling was also slightly more prevalent when the BGS was IN versus OUT. As fish approached the dam, their vertical movement in the water column increased slightly. Meanwhile, smolts' horizontal movement perpendicular to the dam decreased substantially and their horizontal movement parallel to the dam remained relatively constant.

As the season progressed, fish displacement movements increased. The ellipsoidal volume of most fish movements increased from approximately 0.5 m^3 early in the sampling season to nearly 2.0 m^3 at the end of the sampling season. Although more milling took place when the BGS was IN, ellipsoidal volumes were smaller for the BGS IN configuration than the BGS OUT configuration.

Reasons for these behaviors are not readily apparent, although eddies, acoustic noise, and the physical presence of the structures could have been factors that affected how the fish behaved. More fine-scale behavior data on the migrating population are needed to reinforce the data collected to date as this was the first year for DHM analysis.

DISTRIBUTION AND MOVEMENTS OF NORTHERN SQUAWFISH AND SMALLMOUTH BASS DURING OPERATION OF A SURFACE BYPASS AND COLLECTION SYSTEM FOR JUVENILE SALMONIDS LOWER GRANITE DAM, WA

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A prototype surface bypass and collector (SBC) was installed at Lower Granite Dam in winter 1996 to evaluate surface bypass and collection as a means to improve juvenile salmonid passage and survival at Columbia and Snake river dams. To evaluate the potential for increased predation on juvenile salmonids during operation of the SBC, we monitored the distribution and movements of 75 adult northern squawfish *Ptychocheilus oregonensis* and 32 adult smallmouth bass *Micropterus dolomieui* outfitted with radio-transmitters, April to September, 1996-98. Five northern squawfish monitored in the forebay and 12 and 20 smallmouth bass monitored in the forebay and tailrace consistently inhabited nearshore areas. In the tailrace, the distribution of 71 northern squawfish was limited to shorelines and protected low velocity areas when continuous spill was present. Northern squawfish moved into the spillway stilling basin and downstream from the turbines when river flows decreased and there was no spill.

Activity of northern squawfish peaked after dawn and again during the evening, based on hourly monitoring of individuals during consecutive 24-h periods. Light levels during crepuscular and nighttime periods may be advantageous for foraging northern squawfish and daily peaks in salmon smolt numbers occur during periods of darkness.

Losses of juvenile salmonids to predation by northern squawfish and smallmouth bass vary seasonally and depend on river conditions. The potential for predation on juvenile salmonids by northern squawfish in close proximity to the SBC in the forebay, or by smallmouth bass in either the forebay or tailrace, is not very high because of small numbers of predators and they did not congregate near the SBC. In the tailrace, predation by northern squawfish on juvenile salmonids could be significant if river flows are low and there is little or no spill when juvenile salmonids are passing through the SBC and over spillbay 1. At the present time, squawfish abundance is low and that will limit predation.

EVALUATION OF ADULT CHINOOK SALMON PASSAGE AT LOWER GRANITE DAM DURING TESTING AND OPERATION OF A PROTOTYPE SURFACE BYPASS COLLECTOR AND BEHAVIORAL GUIDANCE STRUCTURE, 1997-1998

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In 1996, a prototype surface bypass collector (SBC) and in 1998 a behavioral guidance structure (BGS) for migrating juvenile salmonids were installed at Lower Granite Dam. Mobile tracking and fixed receiver sites were used to monitor radio-tagged adult chinook salmon to evaluate the potential effects the SBC and BGS could have on upstream adult migration. The operation of the surface bypass collector could potentially affect upstream adult migration by creating another opening for fish to fallback over the dam and installation of the behavioral guidance structure could alter migration routes.

Adult salmon were tracked by boat or on foot as they exited the fish ladder on the south shore. A fixed antenna and receiver located 2 km upstream recorded fish as they exited the forebay area. In 1997, 192 chinook salmon were tracked; the majority of fish migrated along the south shore (135) while some crossed in front of the dam to the north shore and traveled upstream (14). Sixteen traveled upstream through the middle of the channel and 22 were located in the vicinity of the surface bypass collector. Four fish were tracked twice (fallbacks that reascended) and 90 had been reported as being recaptured in fisheries or at hatcheries or spawning areas. In 1998, 145 chinook salmon were tracked (85 BGS out, 44 BGS in, and 16 BGS in transition). The majority of fish migrated along the south shore (79) while some crossed in front of the dam to the north shore and moved upstream (31). Sixteen fish were located in the vicinity of the surface bypass collector and 15 were tracked to the behavioral guidance structure. Two fish were tracked twice (fallbacks that reascended) and 43 had been reported as being recaptured in fisheries or at hatcheries or spawning areas.

The SBC and BGS do not appear to have an effect on adult passage. The percentage of fish that crossed to the south and north shore is similar with the BGS in and with the BGS out. Forty-eight percent of fish went up the south shore with the BGS in and 62 percent with the BGS out. Seven percent of the fish crossed to the north shore with the BGS in and 22 percent with the BGS out. The migration route results of 1998 are similar to 1997 (before the BGS was installed 79% south shore and 8% north shore). Fallback rates will be assessed upon completion of the general migration file and compared to previous years.

PREDATOR ABUNDANCE AND SALMONID PREY CONSUMPTION IN LOWER GRANITE RESERVOIR AND TAILRACE

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We compared the relative and absolute abundance, diet composition, and consumption rates of salmonid fishes by smallmouth bass *Micropterus dolomieu and* northern squawfish *Ptychocheilus oregonensis* in the tailrace and forebay of Lower Granite Dam associated with the surface bypass collector and with those from the Snake and Clearwater river arms of upper Lower Granite Reservoir. The relative abundance of smallmouth bass < 174 mm in length was significantly higher in the Snake and Clearwater river arms than in the tailrace and forebay, while smallmouth bass > 1 74 mm in length were generally more abundant in the Snake River arm than in other sampling locations during 1996 and 1997. Northern squawfish >349 mm were most abundant in the tailrace boat-restricted zone, while squawfish <200 mm were most abundant in the tailrace in 1996 and 1997. We found no significant differences in the relative abundance of northern squawfish 200-349 mm in length among reservoir locations in both years. Based on a mark-recapture census we found the absolute density (no/m^{-2}) of smallmouth bass > 1 74 mm in length was highest in the forebay of Lower Granite Dam, Population density of smallmouth bass > 1 74 mm in length was highest in the tailrace. Crustaceans and nonsalmonid fishes were the most abundant food items by weight of both smallmouth bass and northern squawfish from April through August 1996 and 1997. Juvenile salmonids were a food item of insignificant importance to smallmouth bass and northern squawfish diets at any location in Lower Granite Reservoir and tailrace. We did not find evidence of consumption of juvenile salmonid fishes by northern squawfish at the four sampling locations in 1996 and 1997. Consumption rates of juvenile salmonid fishes by smallmouth bass were highest in the forebay (0.0 1 7 smolts/bass/day) in 1996 and in the tailrace (0.0 1 5 smolts/bass/day) in 1997, respectively. We estimate approximately 6,400 and 7,800 juvenile salmonid fishes were consumed by smallmouth bass from April to August 1996 and 1997, respectively. High flows and resulting lower water temperatures and higher turbidity may have contributed to the low levels of predation on juvenile salmonids we observed during 1996 and 1997.

EVALUATION OF ADULT SALMON AND STEELHEAD MIGRATIONS PAST DAMS AND THROUGH RESERVOIRS IN THE LOWER COLUMBIA RIVER

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In 1998, we continued studies of the upstream migration of adult salmon and steelhead past dams, through reservoirs, and into tributaries of the Columbia River basin and placed radio transmitters in 896 spring and summer chinook salmon and in about 1000 fall chinook salmon. We began putting transmitters in spring chinook salmon on 1 April and discontinued tagging summer chinook salmon on 15 July because river temperatures exceeded 70 F. We began tagging fall chinook salmon on 31 August despite continued high river temperatures to avoid missing the main part of the fall run.

Flows in the Columbia and Snake rivers during the spring and summer of 1998 were less than in the previous two years, but there were still significant amounts of spill at the dams because of spill for juvenile passage and peak flows were about 100 kcfs higher than the 15-year average.

The distribution of chinook salmon with transmitters in the Columbia Basin based on our initial queries of the database was similar to the distribution based on counts of salmon at the dams; 40-50% in the lower Columbia, and 25-30% into the mid Columbia and Snake River basins, an indication that our tagging was probably representative. For the 1996 data which has now been analyzed, the preliminary estimates of distribution differed from the final estimates of tagged fish, and were closer to the distributions based on counts of salmon at the dams.

As in past years, a high percentage (92%) of the spring and summer chinook salmon released with transmitters downstream from Bonneville Dam in 1998 returned to the dam and proceeded upstream. We were still tagging fall chinook salmon at the time of the review and do not have estimates of passage.

Some salmon move back downstream past dams on the Columbia and Snake rivers and are referred to as fallbacks. Fallback rates (number of fallback events/number of fish passing dam) of up to 30% have been reported in past years at Bonneville Dam, particularly when large amounts of water was discharged through the spillways. Based on completed analysis of the 1996 data, 14% of the salmon that passed over Bonneville Dam fell back over the dam, but because some fell back more than once, the fallback rate that would be used to correct counts of salmon passing the dam was 16.7% (133 events/795 salmon that passed dam). Rates of fallback were related to the volume of spill. Our preliminary estimates of fallback rates in 1996, 1997, and 1998 at Bonneville Dam of spring and summer chinook salmon were 17.8%, 19.4%, and 12.9%.

In previous years, we reported that significant numbers of spring and summer chinook salmon had fallen back at some of the dams upstream from Bonneville Dam. Based on the completed data for 1996, 13% of the salmon passing The Dalles fell back, 12% of those at John Day, 9% of those at McNary, 8% of those at Ice Harbor, 1% of those at Lower Granite, and 4% of those at Priest Rapids dams. Most (70-85%) of the salmon that fell back at the lower Columbia River dams had used the south-shore (Oregon) fishways. Of all fish that fell back at Bonneville Dam, 82% had passed over the dam through the Bradford Island fishway. For salmon that fell back within 24 hr of passage, 94% had used the Bradford Island fishway.

Because of the high incidence of fallback among salmon using the Bradford Island fishway, in 1997 and 1998, migration routes of salmon and steelhead that exited the Bradford Island fishway were monitored with radio telemetry equipment to obtain baseline data for use in consideration of proposals to reduce fallback at the dam.

Spring and summer chinook salmon and sockeye salmon, and steelhead outfitted with radio transmitters and released downstream from Bonneville Dam were tracked from the Bradford Island fishway exit upriver approximately two kilometers. A radio receiver and antenna located 4 km upstream from the dam was used to record fish as they exited the study area. In 1997, a total of 251 fish (130 chinook salmon, 111 sockeye salmon, and 10 steelhead) were tracked; eight were tracked twice (fallbacks that reascended), 146 were recorded at the upstream receiver site, and 78 had been reported as being recaptured in fisheries or at hatcheries or spawning areas. In 1998, 131 spring and summer chinook salmon were tracked; two were tracked twice (fallbacks that reascended), 115 were recorded at the upstream receiver site, and 37 had been reported as being recaptured in fisheries or at hatcheries or spawning areas.

Of the chinook and sockeye salmon tracked in the Bonneville forebay in 1997, 19% and 12% were estimated to have fallen back. In 1998, the preliminary fallback estimate of chinook salmon tracked in the forebay that fell back is 10 percent. Fish followed four dominant migration routes after leaving the Bradford Island fishway in 1997 and 1998, respectively: (1) Bradford Island shore –spillway - fallback (25 chinook, 13 sockeye, and 1 steelhead; 13 chinook, incomplete data); (2) Bradford Island shore – crossed spillway forebay to Washington shore then upstream (26 chinook, 30 sockeye; 62 chinook); (3) Bradford Island shore – crossed channel to Oregon shore then upstream (20 chinook, 49 sockeye; 21 chinook); (4) fishway exit – crossed powerhouse one forebay to the Oregon shore then upstream (13 chinook, 3 sockeye; 8 chinook).

Of the 795 spring and summer chinook salmon that passed Bonneville Dam in 1996, 77% did not fallback at any of the dams and 23% did fallback at one or more of the dams. Sixty-eight of the fish fell back more than once. The fallback rate for spring chinook salmon was 23% and for summer chinook salmon it was 20% for all of the dams combined.

Salmon that fell back at one or more dams took longer to pass individual dams or groups of dams than fish that did not fall back. For example, median passage times from release for non-fallback salmon at Bonneville Dam was about 2 d versus 6-7 d for salmon that did fall back. From release to passage over Lower Granite Dam, salmon that did not fall back had median migration times of 24-25 d, versus about 32 d for fish that had fallen back one or more times enroute to Lower Granite Dam.

Survival of salmon that fell back at one or more dams to the uppermost monitoring sites and into tributaries in 1996 was about 75%, the same as for all salmon with transmitters. Except for the longer times for fallback salmon to pass the dams, we found no evidence that fallback fish survived at a lesser rate than those that did not fall back.

As in earlier years, most of the spring chinook salmon recaptured in Snake River tributaries in 1998 were tagged at Bonneville in the first half of the run. Salmon returning to some of the other tributaries had slightly different timing at Bonneville Dam.
Analysis of data for the turbine unit 1 test at John Day Dam in 1997 was completed in 1998. The turbine unit was operated alternately at 100 or 150 MW in a randomized block design to evaluate entrances used and time to enter the fishways. Although test conditions limit the power of tests like this, there was no evidence that passage of chinook or sockeye salmon and steelhead differed with operation of the unit at 150 or 100 MW.

Analysis was also completed for the ‘spill for adult passage’ test conducted at John Day Dam in the summer and fall of 1997. Spill of 2000 or 0 was discharged through the spillbay next to the north-shore fishway on alternate days. Entrances used, time to enter the fishways, and time to pass the dam were measured. There was no evidence that time to enter the fishways, the most critical measure, was shortened by spill in the north spillbay.

EVALUATION OF ADULT PACIFIC LAMPREY PASSAGE, SWIMMING BEHAVIOR, AND PERFORMANCE AT BONNEVILLE DAM

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Studies to evaluate passage of adult Pacific lamprey at Bonneville dam were continued in 1998 with the release of 200 transmitter-tagged lamprey into the tailrace of the dam, and special studies to evaluate their swimming behavior and performance. Lamprey with transmitters were monitored in the tailrace and as they proceeded up the ladders to determine where lamprey were having difficulty in their attempts to pass the dam. Modifications to the B-branch entrance to the Bradford Island fishway were evaluated. Tributaries downstream and upstream from Bonneville Dam were searched for lamprey with transmitters.

We evaluated the swimming performance of adult Pacific lamprey *Lampetra tridentata* by modifying the hydraulics and design of an experimental PVC pipe fishway and compared the resulting lamprey passage. Testing facilities at the Bonneville Dam Adult Fish Collection and Monitoring Facility (AFF) consisted of 30 ft. sections of PVC pipe (8 or 12 in. diameter) connected to a downstream introduction tank and an upstream collection tank. A total of 77 test trials were conducted involving 805 lamprey (495 naive, 310 re-tested) during June through August, 1998. Proportions of lamprey that passed through the pipes and total passage times were similar across lower water velocities tested (0.5, 1.0, and 1.75 fps), but proportions that passed decreased and total passage times increased at water velocities $\geq$ 4.5 fps. Proportions of lamprey that passed were higher during nighttime as compared to day, and higher during the earlier period of testing (17-Jun-2Jul98) compared to the later (7Jul-23Jul98). Lamprey had lower passage rates through pipes with 1 ft steps every 10 ft (41%$\pm$16 SE) compared to straight pipes (85.5%$\pm$ 3.8 SE). The lower passage rate was apparently due to high water velocities (6-6.5 fps), low water depth (1-2 in.), and pipe slope (1-on-3 ft.) present within stepped transition sections.

We also observed adult lamprey swimming behavior through submerged orifices using underwater video equipment installed in the AFF bypass ladder during August and September, 1998. Twenty-nine successful lamprey passages and 6 unsuccessful passages were observed after releasing 42 lamprey into the bypass ladder over a period of six days. Total passage time between the area 18 in. downstream of the monitored orifice to 12 in. upstream of the orifice averaged 3.9 minutes ($\pm$ 0.59 SE). This compares to an average of 0.04 minutes ($\pm$ 0.16 SE) observed for adult salmonids. Lamprey swam through the submerged orifice in a repeated series of swimming motions of attaching on the ladder floor using their sucker mouth, surging forward, and then re-attaching.

Adult lamprey will efficiently pass through a straight PVC pipe fishway, however will not pass efficiently through a design including steps as tested. Adult lamprey passage appears to be limited by water velocities $\geq$ 4.5 fps. Efforts to improve adult lamprey passage over dams should include development of reduced velocity.

UPSTREAM MIGRATION OF PACIFIC LAMPREYS (*Lampetra tridentata)* IN THE COLUMBIA RIVER

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Pacific lampreys *(Lampetra tridentata)* are native anadromous fish in the Columbia River Basin. They were widespread and abundant before the development of the Northwest; however, populations of Pacific lampreys have declined since the 1940's. Construction of dams, changes in land use, and changes in the ocean fishery might have affected Pacific lamprey populations. Fish passage facilities at dams are a potential deterrent to the upstream migration of Pacific lampreys. The U.S. Army Corps of Engineers decided to conduct studies to examine Pacific lamprey passage through fishways at Bonneville Dam. The published literature describing the life history of Pacific lampreys tells us that during peak spawning migration (spring) two groups of Pacific lampreys are migrating upriver, some that will spawn that year and some that will spawn the following year. Hormone levels differences in fish could result in drastically different migrational behavior confounding interpretation of radiotelemetry data. To avoid this problem, the maturity of lampreys being tagged must be known. We were asked to design a study that would assist researchers doing radiotelemetry work on lamprey passage to determine the maturity level of the fish they were tagging. We collected Pacific lampreys from the fishway at Bonneville Dam from May through September and at Willamette Falls in July 1998. Some fish have been held alive at the Columbia River Research Laboratory (CRRL) and sampled at two to four week intervals. Length, weight, girth and gonad weight (for mortalities and a portion of fish caught that were sacrificed) were recorded.

Of the adult Pacific lampreys transported to the lab, only one became sexually mature and died while held at the CRRL. This fish (a female) was examined two weeks before she became ripe and at that time showed no external signs of sexual maturity. However, the day she died, she clearly showed external morphometric changes, such as change in skin tone and texture, and the appearance of a fleshy protrusion immediately behind the vent. This fish released gametes and died. It is interesting to note that this fish was collected on 5 May 1998, the first day of trapping for Pacific lamprey radiotelemetry work at Bonneville Dam. This information suggests that most of the fish collected in the fish passageway at Bonneville Dam in 1998 are not going to become sexually mature and spawn in 1998.

If funding is provided for FY 1999, we plan to conduct a series of laboratory and field studies to evaluate the fishway at Bonneville Dam by measuring swimming performance of Pacific lampreys. We would measure metabolic costs and indirect effects of exhaustive stress in these lampreys in the laboratory with EMG radiotags. The output of the EMG tags will be correlated to measurements of metabolic costs. By using the same tags in Pacific lampreys migrating up the fishway at Bonneville Dam, we will be able to measure the overall effects of the fishway. In addition, we will have a direct measures of the relative exertion by the lampreys as the move through sections of the fishway. Specific problem areas should be easily identified using this approach.

EVALUATION OF TEMPERATURE IN ADULT FISHWAYS AND FOREBAYS AT ICE HARBOR AND LOWER GRANITE DAMS

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Water temperatures in adult fishways and forebays of the lower Snake River dams have exceeded 21^o C in recent years. Water temperatures in 1998 exceeded 24^o C. This is near the lethal temperature for salmonids and has caused concern that water temperatures in adult fishways may be acting as an impediment to adult salmonid migration. Water releases from upriver storage reservoirs have been used to augment flows for smolt seaward migration. These water releases, especially from Dworshak Dam reduce water temperatures in Lower Granite Reservoir and could improve conditions for adult passage.

We monitored water temperatures in the forebays and adult fishways of Lower Granite and Ice Harbor dams to determine if water temperatures in adult fishways act as an impediment to fish migration and to determine if a source of cool water exists in the forebays that could be used to lower water temperatures in fish ladders. Beginning in 1995, water temperatures in fish ladders were monitored each year from July through October with temperature recorders set to record temperatures hourly. Recorders were located at entrances to and exits from fish ladders and below make up water diffusers. Maximum temperatures exceeded 21^o C in all years of the study. Temperatures in excess of 24^o C were recorded in 1998. Temperature changes along the length of fish ladder tended to be slight, less than 0.5^o C, but changes of up to 2^o C were observed on a few occasions. The addition of make up water tended to lower water temperatures in the fish ladders, however, differences above and below diffusers were slight.

Temperature profiles in forebays were taken biweekly beginning 1 July. Surface temperatures in excess of 24^o C were recorded and the gradient between surface and bottom temperatures was slight. Temperature at the bottom of the forebay often exceeded 20^o C. There does not appear to be a pool of cool water available in the forebays that could be used to cool water temperatures in the fish ladders.

RELATIVE SURVIVAL OF JUVENILE SALMON PASSING THROUGH THE SPILLWAY AND ICE AND TRASH SLUICEWAY OF THE DALLES DAM, 1998

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Spillway passage at The Dalles Dam is presumed to provide increased protection for migrants as has generally been the case at other Snake and Columbia River dams. The Dalles Dam, however, lacks a bypass system, and therefore achievement of the 80% fish passage efficiency standard has necessitated spilling a high proportion (64%) of river flow during the spring and summer juvenile migration periods. Tailrace conditions at The Dalles Dam, however, differ from those at other dams, in that the stilling basin is relatively short and shallow. These physical characteristics of The Dalles Dam tailrace lead to severe turbulence within the stilling basin during periods of high spill, raising the possibility of physical injury to juvenile migrants. Also, passage of migrants through turbulent shallow water areas may increase vulnerability to predation.

An initial study to determine relative survival of juvenile salmon passing The Dalles Dam spillway during 64% spill was conducted by the National Marine Fisheries Service in 1997. Juvenile coho salmon and subyearling chinook salmon were captured from the Bonneville Dam Second Powerhouse Bypass System, tagged with passive integrated transponders, transported upriver to The Dalles Dam, and then released to pass through The Dalles Dam spillway (test releases) or just downstream of The Dalles Dam (reference releases). As these PIT-tagged fish reached Bonneville Dam, a portion (12% of the coho salmon and 14% of the subyearling chinook salmon) were detected as they passed through the Bonneville Dam First and Second Powerhouse bypass systems. Relative survival estimates for spillway passage were 87.1% [95% confidence interval (CI): 80.4 - 93.9%] for coho salmon and 92.1% (CI: 85.5 - 98.7%) for subyearling chinook salmon. Numbers of fish tagged for the study (about 43,000 coho salmon and about 53,000 subyearling chinook salmon) were insufficient to detect significant differences related to other factors such as spill pattern, location of passage through the spillway, spill gate opening, or flow volumes.

In 1998, the second year of the study, we used similar methodology to obtain estimates of relative survival for coho salmon and subyearling chinook salmon passing The Dalles Dam spillway during 30% spill, 64% spill, and for sluiceway passage (30% spill, daytime spill pattern), tagging about 64,000 coho salmon and 80,000 subyearling chinook salmon. Preliminary data show 11.5% of the coho salmon and 4.8% of the subyearling chinook salmon used in the study were detected passing Bonneville Dam. Spring tests resulted in the following relative survival estimates and 95% confidence intervals for coho salmon: sluiceway passage, 97% (86-110%); spillway passage at 30% spill, 100% (90-110%); spillway passage at 64% spill, 87% (80-94%). Summer tests showed the following relative survival estimates and 95% confidence intervals for subyearling chinook salmon: sluiceway passage, 91% (80-98%); spillway passage at 30% spill, 85% (70-98%); and spillway passage at 64% spill, 70% (61-80%). Probability values associated with the higher observed relative survivals for 30% spill than for 64% spill levels were P=0.036 for coho salmon and P=0.052 for subyearling chinook salmon (Analysis of Covariance).

Relative survival estimates for coho salmon passing The Dalles Dam spillway at 64% spill levels were identical in 1997 and 1998 (87%). In contrast, relative survival of subyearling chinook salmon decreased from an estimated 92% in 1997 to 70% in 1998. In 1998, relative survival of sluiceway releases was surprisingly high (97% for coho salmon and 91% for subyearling chinook salmon). We suggest that an additional year of testing with PIT-tag technology would be useful to confirm the sluiceway and 30% spill results. Use of other research methods would be called for to determine location and cause of mortalities.

THE EFFECT OF SPILL LEVEL ON FISH PASSAGE EFFICIENCY AT THE DALLES DAM IN 1998

Marvin Shutters, US Army Corps of Engineers, Portland District

The effect of spill level on the number of migrating juvenile salmon passing The Dalles Dam was estimated with fixed aspect hydroacoustic techniques. The percent of project discharge spilled alternated daily between 30% and 64%. During low per bay spill, which occurred during the day under 30% spill fish near the surface were not committed to passing and were likely overestimated. Therefore, spillway estimates for 30% days will not be used in analyses. Data on turbine and sluiceway passage give no indication of bias, and should not have been effected by changes in spill volume or percent. Mean daily sluiceway and turbine passage were both greater at 30% spill than 64% spill. Mean daily sluiceway passage increased by 98% or 634,165 fish in Spring; whereas, turbine passage increased by 80%, or 97,554 fish. Mean daily sluiceway passage increased by 75% or 367,735 fish in Summer; whereas, turbine passage increased by 28% or 39,992 fish. We estimated passage efficiencies without spillway data for 30% spill days by assuming equal numbers of fish passed the project under each condition. In Spring, 40% of the fish passed through spill and 51% through the sluiceway during 30% spill; 64% spill resulted in 69% passing in spill and 26% through the sluiceway. In Summer, 47% of the fish passed through spill and 44% through the sluiceway during 30% spill; 64% spill resulted in 68% passing in spill and 25% through the sluiceway. Fish passage efficiency was higher at the high spill level in both season; however, these data combined with the NMFS PIT survival study indicate that project survival may be as much as 10% greater at 30% then 64% spill. Further passage and survival studies are needed to determine the optimal operation of the project and determining the importance of continuing the surface program.

MOVEMENT, DISTRIBUTION, AND BEHAVIOR OF RADIO-TAGGED JUVENILE CHINOOK SALMON AND STEELHEAD AT JOHN DAY DAM, 1998

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In 1998, we used radio telemetry to examine the movements and behavior of yearling and subyearling chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) in the tailrace and forebay of John Day Dam. Tailrace study objectives were to describe the behavior of juvenile salmonids passed through the study spillbays (2, 10, and 18) to determine residence time in the tailrace based on route of passage and describe the hydraulic conditions likely experienced by fish. The forebay component of the study was designed to determine the general movements and behavior of fish in the forebay, and route and timing of fish passage.

During the spring outmigration, we released 147 yearling chinook salmon and 154 yearling steelhead in 11 release groups into the John Day Dam tailrace. Generally, tagged fish released from spillbay 10 had the lowest mean residence times in the tailrace, while fish released from bay 18 had the highest. The mean residence time for tagged chinook salmon and steelhead released from bay 10 was 4.3 min, as compared with 7.3 min (chinook salmon) and 9.9 min (steelhead) for fish released from bay 18. The mean travel rate of radio-tagged fish was highest, and differences in travel rate base on release site were most prominent within 0.7 km of the dam (tip of the navigation lock). As fish moved downriver, travel rates decreased and the influence of release site was reduced.

For the forebay study, we released 119 yearling chinook salmon and 120 steelhead from McNary Dam in four release groups. Based on last known location, approximately 77% of chinook salmon and 67% of steelhead were estimated to have passed the dam through the tainter gates. The remaining chinook salmon (23%) and steelhead (33%) were last contacted near, and assumed to have passed the dam through the turbines or juvenile bypass system. The median residence time for yearling chinook salmon was 1.7 h and ranged from <0.01 h to 99.1 h. For steelhead, the median residence time was 9.6 h and ranged between < 0.01 and 156.0 h. Median residence times were highest for fish that arrived at the dam between 0500-1700 hours.

During the summer outmigration, we released 152 subyearling chinook salmon into the tailrace in five release groups. Subyearling chinook salmon displayed trends in behavior similar to spring migrants. Fish released from bay 10 had the lowest mean residence times in the tailrace (4.8 min), while fish released from bay 18 had the highest (7.3 min).

For the summer outmigration forebay study, we released 119 subyearling chinook from McNary Dam in four release groups. Approximately 73% of the radio-tagged fish were estimated to have passed through the spillway and 27% through the powerhouse or juvenile bypass system. The median residence time for subyearling chinook salmon was

6.8 h and ranged from <0.1 h to 183.2 h. Fish that arrived at the dam between 0500 - 1300 hours had the highest median residence times.

In all components of the study, the spring and summer outmigrants generally showed similar behaviors. In the forebay, the majority of fish during both outmigration periods were estimated to have passed the dam through the spillway. In the tailrace the mean residence time was less than 10 min for all groups, and significant delays were uncommon. Velocity instruments released from our study spillbays showed predominant flows generally moved north as they moved downriver. Based on our findings, we would estimate that fish passing through the north and middle spillgates (gates 1-10) likely become entrained in the predominant flow and pass readily out of the immediate tailrace environment.

HYDROACOUTIC ESTIMATES OF SPILL EFFICIENCY AT JOHN DAY DAM IN 1998

Marvin Shutters, US Army Corps of Engineers, Portland District

Spill efficiency was estimated at John Day Dam was estimated with fixed aspect hydroacoustic techniques. Night time spill up to 160 kcfs was designed to pass juvenile salmon safely. Daytime spill occurred when river flow exceed powerhouse capacity, which was much of Spring and little of Summer. Mean daily spill efficiency was 66% in Spring and 60% in Summer. Day time spill levels that ranged from 43 to 153 kcfs with efficiencies ranging from 65% to 97% in Spring. Daytime spill only occurring on 7 days in the summer at levels from 16 to 96 kcfs and mean spill efficiency of 68%. Significantly more fish pass per volume of spill during the day than at night. Spring mean effectiveness was 4.25:1during the day; contrasted to 1.17:1 during the night. This study strongly suggests that 24 hour spill would benefit survival past the project, assuming that spillway is the safest route.

EVALUATION OF THE EFFECTS OF SPILL DEFLECTORS AT ICE HARBOR DAM ON PASSAGE OF ADULT SALMON

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Spill deflectors or flip lips were not added to the spillbays at Ice Harbor Dam until 1997 due to concerns that deflected spill would create flow patterns that would be detrimental to adult passage and the belief that daytime spill would be minimal at Ice Harbor Dam. In 1996, uncontrolled spill and spill for smolt passage contributed to dissolved gas levels that exceeded current standards. High dissolved gas levels may lead to losses of adults and juveniles due to gas bubble disease. Spill deflectors were added to spillbays four through seven in 1997 and to spillbays two, three, eight and nine in 1998.

The addition of spill deflectors to spillbays at Ice Harbor Dam appears to have reduced dissolved gas levels at moderate levels of spill but not at levels in excess of 100 kcfs. We monitored entrance use and the time needed for adult chinook salmon to approach and enter fishways to determine if the addition of spill deflectors had any effect on adult migration.

In 1996, approximately 15 - 20% of adult chinook salmon first approached Ice Harbor Dam at the north shore entrances, 10 - 15% at each of the floating orifice gates, the south shore entrances and the north powerhouse entrances. Orifice gate ten was used by relatively few fish in 1996. In 1997, most fish first approached the dam on the south shore. Approximately 20% of adult chinook salmon first approached the dam at the south shore entrances and 25% at orifice gate one. Approximately 5% of adult chinook salmon first approached Ice Harbor Dam at each of the orifice gates at the north end of the powerhouse, the north powerhouse entrances and the north shore entrances in 1997.

The time for adult chinook salmon to approach the dam after entering the tailrace at Ice Harbor was similar in both 1996 and 1997 and did not appear to be correlated with volume of spill.

THE PASSAGE OF JUVENILE SALMONIDS THROUGH KAPLAN TURBINES

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The objective of this project is to test the hypothesis that juvenile migrants follow stream-tubes during passage through the intake portion of a Kaplan hydro-turbine. The means selected to acquire data for test of the hypothesis are:

1. observations of neutrally buoyant particles during passage through the intake of a 1:25 physical model of a Kaplan turbine,
2. and tracking juvenile salmonids bearing an ultrasonic transmitter during passage through a full scale Kaplan turbine.

During FY98 there were several completions of major project elements. These completions were:

1. acquisition of video images of the movement of neutrally buoyant particles through the Kaplan turbine physical model,
2. development of the analytical methods and software to optimize the configuration for the ultrasonic tracking system, estimation of the location of the transmitter given output from the tracking system, and the analytical methods and software to estimate the probability tube for the movement of tagged salmonids passing though the turbine intake,
3. bench testing and calibration of the ultrasonic tracking system,
4. design and testing of ultrasonic micro-transmitter configurations.

All of the elements necessary to track juvenile salmonids through an operating Kaplan turbine are nearing completion. Given the current status of the various elements it would be possible to perform the through turbine intake tracking experiments in FY99.

THE EFFECTIVENESS OF STROBE LIGHTS FOR VERTICALLY DISPLACING JUVENILE SALMON OUT OF FLOW ENTERING A 4.3 X 4.9m FILLING INTAKE AT HIRAM M. CHITTENDEN LOCKS, SEATTLE

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In FY 98, we evaluated the use of strobe lights for vertically redistributing salmon smolts in front of a 4.3 x 4.9 m culvert used to fill a 24.4 x 251.5 x 15.2 m deep navigation lock chamber in Seattle, WA. Flows into the culvert during low tides were up to 2200 cfs, with maximum water velocities of 5.5 fps. We installed ten strobe light flash heads around the perimeter and in front of the north filling culvert. We ran strobe lights at 600 watts with a pulse rate of 300 flashes per minute. Fish densities near the culvert entrance were monitored hydroacoustically using a pair of 6-degree single-beam transducers mounted on a pole and aimed down toward the center of the intake. Density estimates of fish in the acoustic beams were based on echo integration intervals of 15 seconds in each of 11 1-m depth strata. Strobe lights were evaluated using paired on and off treatments during day (n=32) and night (n=31). Nighttime strobe light evaluations were inconclusive due to low numbers of fish near the culvert entrance during both test and control treatments. We evaluated effects before and during fill events.

<u>10-minutes before fill</u>: In control treatments, juvenile salmon were mostly distributed within the bottom 5 m's of the acoustic beams, with the greatest mean density observed in the deepest strata (12-13 m). With strobe lights turned on, the fish distribution shifted upward, with the greatest mean density observed in the 5-6 m depth strata. Mean fish densities at the depth of the culvert (8-13 m) decreased by over 96% during strobe light-on

treatments. Based on paired t-tests, mean fish densities in 1-meter strata below a depth of 8 m were all significantly lower (alpha = 0.05) during on treatments than during off treatments.

<u>During fill events</u>: In control treatments, the distribution of juvenile salmon was observed to be relatively uniform, with greatest mean densities 8-10 m's from the transducers. During strobe light-on treatments, juvenile salmon were distributed higher in the water column, with greatest mean densities occurring 5-7 m from the transducers, and very low densities at the depth of the culvert. Mean fish densities at the depth of the culvert decreased by 87% during strobe light-on treatments. Based on paired t-tests, mean fish densities in 1-meter strata below a depth of 9 m were all significantly lower (alpha = 0.05) during on treatments than during off treatments.

TWO-DIMENSIONAL HYDRODYNAMIC, WATER QUALITY, AND FISH EXPOSURE MODELING OF THE COLUMBIA AND SNAKE RIVERS

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The U.S. Army Corps of Engineers (USACE) Dissolved Gas Abatement Program (DGAS) is studying options to reduce dissolved gas supersaturation (DGS) associated with federal hydroelectric dams on the Columbia and Snake rivers. In order to address the complex nature of DGS exposures numerical models of gas transport, gas mixing, and dynamic gas bubble trauma are being developed by Battelle, Pacific Northwest Division for the USACE. These models couple hydrodynamics, temperature, DGS production, DGS transport, and fish distribution information with a dynamic gas bubble trauma mortality model which will provide an estimation of cumulative mortality in fish populations passing Columbia and Snake River dams.

The downstream movement and mixing of dissolved gas produced at each project is being modeled using a two-dimensional (2D depth-averaged) unsteady flow and transport model. The model is applied on a pool-by-pool basis to the domain from Lewiston, ID and Kennewick, WA at the upstream boundaries to Portland, OR at the downstream boundary. The 2D model simulates the depth-averaged (plan view) values of water surface elevation, velocity, temperature, and gas concentration. The 2D model will be used to evaluate the details of specific gas abatement alternatives such as changes in spill patterns and the resultant effects on velocities, gas mixing, and fish exposure. These models are physics-based and can be applied to both the current river system configuration and to other alternatives such as natural river configuration.

The model has been applied to several field study periods for each pool. Included herein are example model results for the McNary pool during the summer 1996 study period. Figure 1 shows the comparison between computed and measured depth-averaged velocities at one transect in the area of the Columbia/Snake River confluence. The spatial distribution of dissolved gas saturation is shown in Figure 2. This figure shows the boundaries between the spill/powerhouse water in the Snake River and the Columbia/Snake river water.

The integration of the physical and biological models is done using a model that tracks the space-time position and exposure history for groups of fish (individual exposure model). The FINS (Fish Individual-based Numerical Simulator) model provides a detailed picture of how different gas abatement alternatives affect exposure. FINS works by tracking large numbers of fish groups through each pool as "particles" moving according to user defined rules. The 2D hydrodynamic and transport model provides the required information about the river environment, in this case simulated distributions of velocity, temperature, water depth, and dissolved gas saturation. The space-time position of each fish group is recorded as well as their exposure history to dissolved gas (see Figures 3 and 4). This approach is flexible in that different sets of user defined fish behavior rules can be assigned and directly compared using the same physical setting (velocity, temperature, and

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dissolved gas). Examples of "fish rules" include relative movement versus water particle movement, differences in day/night movement, species dependent behavior, different depth distributions, and site specific behavioral differences.

Currently, the model has been configured for each pool. The calibration and verification simulations are now in the final stages of completion.

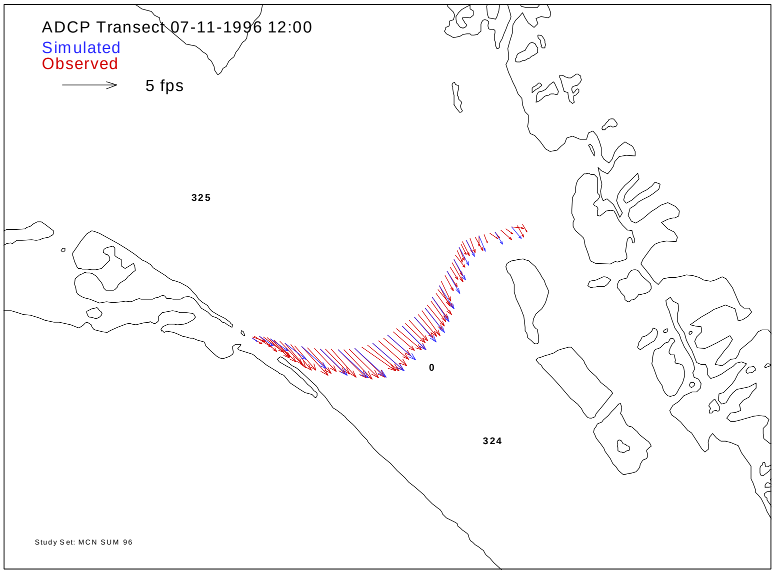

Figure 1. Simulated and observed depth-averaged velocities at the confluence of the Columbia and Snake Rivers on 7-11-1996.

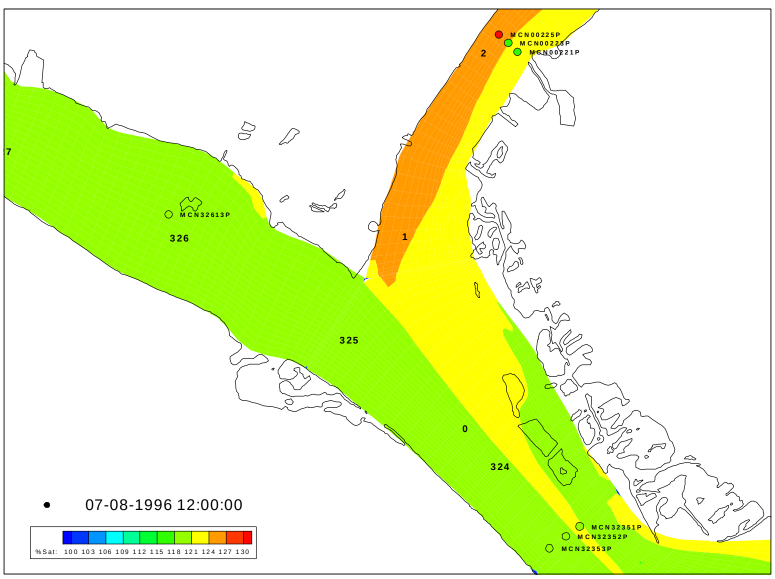

Figure 2. Snapshot of the total dissolved gas distribution at the confluence of the Columbia and Snake Rivers on 7-8-1996. The field monitors (circles) are color coded to their measured saturation.

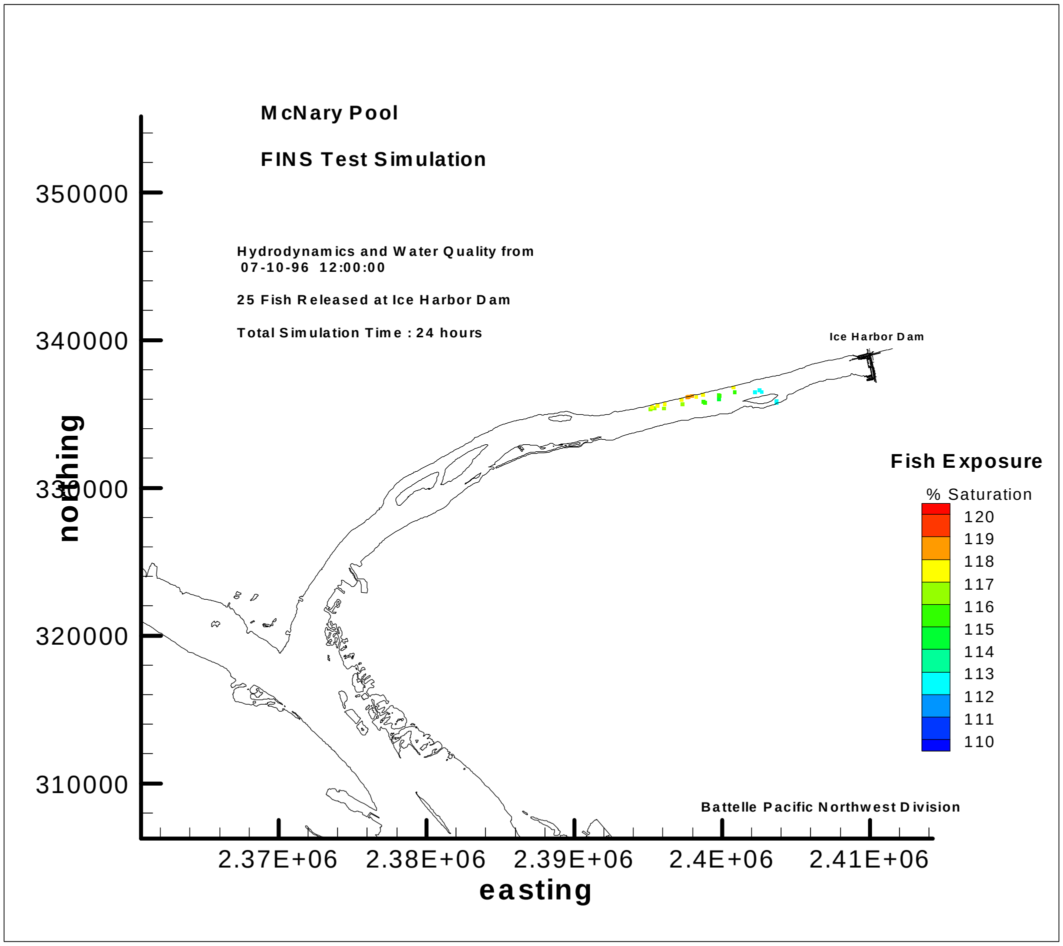

Figure 3. Fish distribution 1 hour after release at Ice Harbor Dam. The fish particles are colored according to the level of dissolved gas exposure at that location.

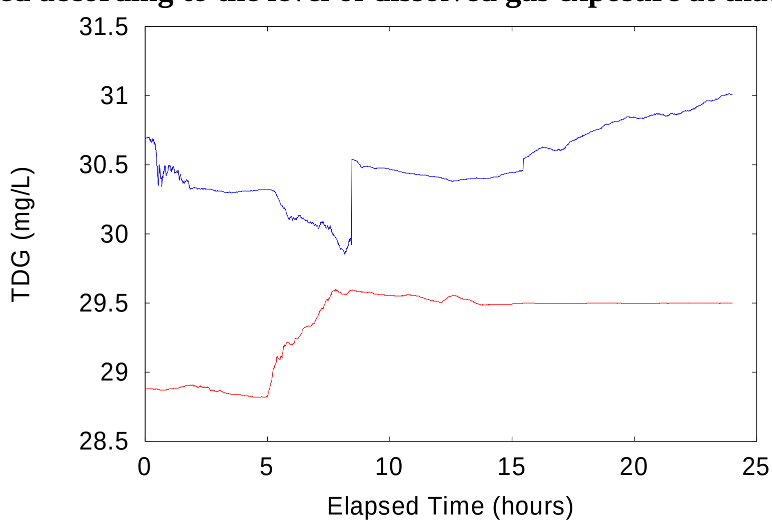

Figure 4. Dissolved gas concentration exposure logs for 2 randomly selected fish.

MECHANICAL INJURY WITH EMPHASIS ON EFFECTS FROM SPILLWAYS AND STILLING BASINS

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The U.S. Army Corps of Engineers (USACE) is in the process of identifying and comparing alternatives for minimizing the impacts of spills at hydroelectric dams in the Snake and Columbia rivers on downstream migrating fish, including juvenile salmon and steelhead. Traditionally, spillways have been used primarily when river discharges exceeded the capacity of the powerhouse, or when regional power demands were substantially lower than the generating capacity of the Snake and Columbia River dams. The duration and magnitude of spilling has increased as a result of experimental flow measures which have been implemented to improve the downstream passage of juvenile fish in these lower Columbia and Snake rivers. These spills are intended to increase survival by decreasing the passage time of downstream migrating fish, and by passing more fish over spillways instead of through powerhouse turbines where injury and mortality rates are thought to be relatively high.

Unfortunately, these spills have also increased the potential for injury and mortality to fish resulting from total dissolved gas (TDG) supersaturation. For this reason, the National Marine Fisheries Service (NMFS) requested the USACE to identify and evaluate potential structural and operational changes to Columbia and Snake river dams which could be used to reduce TDG levels occurring under the current spill program (NMFS 1995). A Gas Abatement Workshop was held during October 1996 by the USACE Portland and Walla Walla districts to review potential alternative gas abatement measures which could be used to improve fish survival during spill events at Columbia and Snake River dams (USACE 1997). Two areas of concern were identified regarding fish survival and spillway passage: 1) achieving reductions in TDG levels which would effectively reduce injury and mortality due to gas bubble trauma (GBT); and 2) mechanical injury and mortality directly or indirectly resulting from passage through a spillway and stilling basin, including those resulting from proposed gas abatement measures. The expert panel attending the Gas Abatement Workshop identified the need for estimating and comparing the mechanical injury of fish in spillways and stilling basins which could result under a number of gas abatement alternatives, including:

- Installation of flow deflectors;
- Installation of flip buckets;
- Raising the elevation of the stilling basin;
- Raising the elevation of the tailrace;
- Construction of submerged passageways; and
- Construction of auxiliary passageways or a side channel.

The USACE is currently pursuing three avenues for gas abatement. These include: reduction in the mass of total dissolved gas produced (deflectors, raised stilling basin), minimize new gas production (submerged passageways, submerged gates, turbine flows), and flow degassing (raised tailrace). Flow (spillway) deflectors, which are concrete sills positioned along the lower end of a spillway, minimize plunge depth by focusing water released from a spillway into a horizontal jet. These devices have been found to be an effective method for reducing TDG levels, and for this reason have been installed at a number of dams on the lower Columbia and Snake rivers (USACE 1996). Their effectiveness, however, is limited to a design operating range. Outside their design range, flow overshoots the deflectors and plunges into the tailrace entraining air and producing high dissolved gas levels.

The purpose of this study was to provide a better understanding of the mechanical injury of fish passing through spillways and stilling basins based upon the data and information provided in the current literature. A literature review identified 67 documents that directly or indirectly pertain to the mechanical injury of fish in spillways and stilling basins. This literature review was intended to: 1) describe the types of injuries sustained by fish passing through spillways and stilling basins; 2) compare injury and mortality rates observed at different dams which have been directly or indirectly attributed to spillway passage, including those with gas abatement structures such as flow deflectors; 3) identify the physical factors and conditions occurring within the spillway and stilling basin environment which have been reported to injure and kill fish; and 4) describe the relationships between these physical variables and injury and mortality rates.

A number of factors have been identified from the literature that may cause physical or mechanical injuries to fish in spillways and stilling basins. These factors are:

- *Rapid pressure change*
- *Rapid deceleration*
- *Shearing effects*
- *Turbulence*
- *Striking impacts*
- *Scraping and abrasion*

The extent of the injuries sustained by a fish while passing through a spillway and stilling basin is related to several factors, including: 1) the magnitude of the physical forces to which the fish are exposed; 2) the length of time during which the fish is exposed to these forces; and 3) the susceptibility and resiliency of the fish to injury.

Stilling basins have traditionally been designed to maximize energy dissipation and to confine the physical area in which this dissipation occurs. Attainment of these objectives results in an efficient and cost effective spillway design. Unfortunately, achievement of these objectives also tends to maximize injury to fish. All of the sources of mechanical injury to fish become more pronounce with increasing energy dissipation. Turbulence, hydraulic shear, fluid deceleration, and rapid pressure changes are all necessary components to achieve the energy dissipation. Increased energy dissipation rates are achieved through the addition of baffle blocks or sometimes incorporation of natural rock features for a specific site. Besides increasing energy dissipation rates which introduces more potential for fish injury, these features of stilling basins also provide increased striking potential risk.

A variety of laboratory and field investigations have been conducted that provide valuable information about injury to fish passing through spillways. Some relationships between water velocity (or dam height) and injury levels can be inferred from these studies. The data are confounded, however, by broad statistical error bands and site specific considerations that make it difficult to define relationships between physical characteristics at spillways and injury to fish. Previous investigators have not focused on attempting to conduct their test to aid in identifying these relationships. Future efforts should concentrate on developing a mechanistic understanding of injury to fish passing through spillways. Detailed investigations into the hydraulics of spillways and stilling basins are warranted to advance our understanding.

EVALUATION OF EXTENDED-LENGTH BAR SCREENS AT BONNEVILLE DAM FIRST POWERHOUSE

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During spring and summer 1998, research was conducted at Bonneville Dam First Powerhouse to determine levels of improvement in fish guidance efficiency (FGE) and orifice passage efficiency (OPE), and levels of descaling and injury using three extended-length submersible bar screens (ESBSs) installed in Turbine Unit 8. Operating gates were raised in the A and C slots of Unit 8 to further improve FGE by increasing flows into the gatewell (gate was removed in Slot B to accommodate fyke-net frame for FGE testing).

In 22 tests conducted from 24 April to 19 May, FGE for yearling chinook salmon averaged 72% (SE = 1.9). For subyearling chinook salmon, steelhead, coho and sockeye salmon, FGE was 67, 85, 80, and 51%, respectively. Improvement in FGE with the ESBS and a raised operating gate compared to FGE with the standard-length submersible traveling screen (STS) and a stored operating gate (1991 test results) was approximately 30% (FGE units) for each species. In a direct comparison during the same time period, OPE with an ESBS and raised operating gate in Slot 8A (90%) was significantly higher than with an STS and stored gate in Slot 9A (80%).

During the spring migration, there was no significant difference in mean descaling for yearling chinook salmon between Unit 8 with ESBSs (9%) and Unit 9 with STSs (8%). Descaling with the ESBS for subyearling chinook salmon, steelhead, coho and sockeye salmon averaged 2, 9, 5, and 22%, respectively, with no significant difference in descaling between the two units for any species. In both units, gill and head injuries combined were less than 1% for all species except sockeye salmon, which were just over 1% for both units.

From 22 June to 17 July, FGE, OPE, and descaling tests were conducted with ESBSs again in Unit 8 and STSs in Unit 9. For subyearling chinook salmon, FGE averaged 55% (SE = 2.0) from 22 June to 27 June and 27% (SE = 2.1) from 29 June to 17 July. In tests in July 1988 and 1989, FGE for subyearling chinook salmon averaged 11 and 4%, respectively (in Unit 3 with STS and stored operating gate).

For subyearling chinook salmon during the summer migration, OPE averaged 97% with the ESBS and 98% with the STS. Descaling averaged 3% with the ESBS and 2% with the STS and injury rates averaged less than 1% in both units.

FISH GUIDANCE EFFICIENCY OF EXTENDED-LENGTH SUBMERSIBLE BAR SCREENS IN TURBINE INTAKES AT LOWER GRANITE DAM IN SPRING 1997 AND 1998

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We measured fish guidance efficiency (FGE) of extended-length submersible bar screens (ESBSs) in turbine intakes at Lower Granite Dam, Snake River, Washington in spring 1997 and 1998. Salmon and steelhead smolts passing through an intake at Lower Granite Dam may be guided by the ESBS into the juvenile bypass system or pass unguided into the turbine. The ESBSs, installed in 1996, are 40 ft long in comparison to the 20-ft long intake screens used previously. Our objective was to document FGE of the ESBSs for the run-at-large. Total project FGE estimates were made in 1997 and 1998. We used single-beam, 420 kHz hydroacoustic systems to estimate separate passage rates for guided and unguided fish. Overall FGE was 87.4 +/- 0.1% in spring 1997 and 83 +/- 0.03% in 1998. FGE varied among the six intakes sampled, ranging from 69% to 93%. Information on ESBS performance in conjunction with other smolt protection measures, such as surface bypass and spill, were evaluated as part of the regional process in the Pacific Northwest to restore salmon populations.

Topic: Smolt Bypass; Fisheries Management

Preference: Oral presentation

Status and Association to AFS: All authors are professionals and all, except Barila and Skalski, and Wik, are AFS members.

EVALUATION OF OUTLET FLOW-CONTROL DEVICES AND METHODS OF DEBRIS CONTROL AT MCNARY AND LITTLE GOOSE DAMS, 1998

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As originally proposed, we were to test the effects of an orifice shelter on orifice passage efficiency (OPE) and descaling at McNary Dam through the spring and summer outmigration. Due to construction setbacks and delivery problems, the Corps of Engineers did not receive the orifice shelters at McNary Dam until 29 June and we began limited testing in July.

As an alternative plan we conducted OPE and descaling tests at McNary Dam during the spring outmigration, testing the effects of the outlet flow-control (OFC) device at both 60 and 80 MW loads. During similar tests in Units 4 and 5 during 1997, we found OPE to be higher at the 80 MW load than at 60 MW. However, descaling was also higher at the 80 MW load. Descaling was reduced by the OFC for subyearling chinook salmon at the 80 MW load.

Test results in 1998 supported the 1997 findings. Yearling chinook salmon OPE and descaling were both higher at the 80 MW load. Orifice passage efficiency adjusted means were 61.0 and 82.8% at 60 and 80 MW, respectively. The OFC reduced the effects of the 80 MW load on descaling for yearling chinook salmon, but not for the 60 MW load. Descaling adjusted means at the 60 and 80 MW loads were 4.5 and 10.8%, respectively, with the OFC off and 6.2 and 8.3%, respectively, with the OFC on.

Limited testing of the orifice shelter was delayed due to large numbers of subyearling chinook salmon in early July plus equipment problems. We conducted four tests during the week of 13 July, but had to end testing due to warm water conditions in the gatewells. No conclusions were made with the limited data gathered during that week.

The study at Little Goose Dam was designed to evaluate the effects of an enlarged orifice (14" diameter compared to the standard 12" diameter) on fish condition (descaling and external injury) and also debris accumulation within a gatewell. Descaling monitoring was done by releasing marked (PIT-tagged) hatchery yearling chinook salmon into gatewells and recapturing the marked fish at the juvenile collection facility for observation. Debris accumulation was monitored through daily observation of the orifices in juvenile bypass system.

Fish monitoring results were limited due to equipment failures and reduced numbers of hatchery spring chinook outmigrants. The PIT-tag detection-by-code system failed during some of the releases. We did release a total of 1,392 PIT-tagged hatchery spring chinook salmon, 680 in the control gatewell (2A) and 712 in the test gatewell (1A). We recovered 367 and 343 (54 and 48%) fish, respectively. Only one of the recovered fish showed any sign of descaling or injury. On 13 May, the orifice in gatewell 1A (14" diameter) plugged. This occurred after a period of high flow and subsequent increased debris load. This event demonstrated that enlarging the orifices (by 2") will not solve the problem of intermittent orifice plugging. An air-operated knife gate shear also being tested as a possible method of unplugging orifices was not effective in this case because the debris had accumulated within the walls of the orifice.

POST-CONSTRUCTION EVALUATION OF THE NEW JUVENILE BYPASS SYSTEM AT JOHN DAY DAM, 1998

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The John Day Dam sampling and bypass facility was completed and ready for operation at the beginning of the 1998 spring outmigration. The facility is designed to bypass juvenile and adult fallback salmonids around the powerhouse and return them to the river. The pre-existing submersible traveling screens, gatewell orifices, and conduit were retained with the new system. The new bypass system begins just downstream from the tainter gate, where the conduit exits the powerhouse and an elevated flume carries water and fish to the primary dewatering structure. Unique to this project is a hydraulic jump designed to slow the water velocity at the dewatering structure and a "dry" separator to segregate adult and juvenile fish.

Objective 1 was to evaluate the condition of juvenile spring chinook salmon and juvenile and adult steelhead after passage through the facility. The first task was to release juvenile chinook salmon and steelhead into the bypass conduit at several locations along the powerhouse and elevated flume/primary dewaterer. A small number of fish incurred injuries during these releases, most of which can be attributed to the release hose at one of the release locations. Overall, we found no significant impacts to juvenile chinook salmon and steelhead condition during passage from the powerhouse to the sampling facility. Juvenile steelhead did hold up in the area of the primary dewaterer for a period of time ranging from several hours to several days.

Adult steelhead evaluations were not conducted this year due to deficiencies in the current release flumes for adult salmonids that have been diverted into the sampling facility. Modification of this area is planned, allowing this task to be completed in 1999.

Blood samples were collected from juvenile chinook salmon and steelhead to evaluate changes in serum concentrations of cortisol, glucose, and lactic acid. Samples were taken from both species at gatewell, pre-separator, and pre-sample tank locations. Results of these analyses are pending.

Objective 2 was to evaluate the reliability and efficiency of the sampling system. In river PIT-tagged fish were monitored to compare the percentage of fish collected in the sample tank to the sample rate set by the programmable logic controller (PLC). The final results of this evaluation are pending, though at sample rates of 0.67, 2.0, 3.33, 5.0, and 10.0% the observed sample rate was lower than the PLC set rate and at sample rates of 1.0 and 1.33% the observed sample rate was higher than the PLC set rate. The significance of these differences is being evaluated.

Objective 3 of the proposal was to evaluate the outfall flume of the bypass facility. It was decided by National Marine Fisheries Service and Corps of Engineer personnel that this objective would be completed by Corps of Engineer personnel at the project.

EVALUATION OF JUVENILE SALMONID TRANSPORTATION, 1998

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In 1998, we continued to research the potential benefits of transportation to increase survival of juvenile salmonids. We conducted the third year of smolt marking to evaluate inriver migration vs. transportation of yearling chinook salmon smolts PIT tagged at Lower Granite Dam, and recovered adult spring/summer chinook salmon PIT tagged as smolts in 1995 and 1996.

From 6 April to 29 June 1998, we PIT tagged 70,651 fish for release into the Lower Granite Dam tailrace through the bypass outfall and 45,441 fish for transport and release below Bonneville Dam. Post-marking delayed mortality (24 hour) averaged 1.1% for the period. Of the fish released inriver, we detected (first-time detections only) 70.2% of the release at Little Goose, Lower Monumental, and McNary Dams combined. Calculations of transport to inriver migrant ratios will be made when adult returns of these groups are complete in summer 2001.

At Lower Granite Dam, we recovered adult spring/summer chinook salmon PIT tagged in 1995 and 1996. For the 1995 study, all adult returns are complete. Through 31 July, we recovered a total of 541 (450 hatchery and 91 wild) transported fish and 324 (275 hatchery and 49 wild) inriver fish (1.3 times more inriver than transported fish were PIT tagged and released as smolts). We also recovered 40 (25 hatchery and 15 wild) adults that were released as inriver fish, but were subsequently collected and transported from a downstream dam. The transport/inriver ratio (T/I) for hatchery fish was 1.9, with a 95% confidence interval of 1.7-2.1. For wild fish, the T/I was 2.1, with a 95% confidence interval of 1.7-2.6.

For the 1996 study, adult returns are incomplete. So far, we have 32 (26 hatchery and 6 wild) transported and 38 (35 hatchery and 3 wild) inriver fish (1.5 times more inriver than transported fish were PIT tagged and released as smolts). We also recovered 3 (2 hatchery and 1 wild) adults that were released as inriver fish, but were subsequently collected and transported from a downstream dam. The T/I for hatchery fish was 1.2, with a 95% confidence interval of 0.9-2.3. For wild fish, the T/I was 2.7, with a 95% confidence interval of 0.7-5.8.

ESTUARINE RECOVERY OF PIT-TAGGED JUVENILE SALMONIDS, 1998

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In 1998, we continued deployment of a specialized trawl containing a passive integrated transponder tag (PIT-tag) detector in the Columbia River estuary at Jones Beach (RKm 75) for interception of PIT-tagged juvenile salmonids. The PIT-tag detector/trawl was deployed and operational a total of 321 hours between 17 April and 5 June. We detected 65 sockeye salmon, 353 coho salmon, 3,794 chinook salmon, 541 steelhead, and 91 fish of undetermined species as they had no release information in the PTAGIS database.

We detected 1,145 PIT-tagged spring/summer chinook salmon marked for the Snake River Transportation Study; 297 transported and released downstream from Bonneville Dam and 848 released for inriver migration from Lower Granite Dam. There were significant differences in passage times at Jones Beach for the two study fish groups. Respective 10th, 50th, and 90th percentile travel times to Jones Beach were 1.6, 2.5, and 3.8 days for transported groups and 13, 19, and 28 days for inriver groups. The longer, more uniform period of availability for fish released at Lower Granite Dam probably accounted for the increased number of detections for these fish compared to transported fish. During the 154 km migration to Jones Beach, transported fish apparently did not disperse; thus these fish produced a patchy distribution and a detection rate that was affected by duration and time of daily sampling.

During the peak migration period of spring/summer chinook salmon, we averaged about 2% detection of PIT-tagged fish previously detected at Bonneville Dam. The survival estimate of fish released at Lower Granite Dam to the tailrace of Bonneville Dam was 68% (95% CL 57% to 79%).

Median travel time to Jones Beach for barge-released PIT-tagged spring/summer chinook salmon was significantly slower than for barge-released radio-tagged spring/summer chinook salmon (median 2.5 d versus 2.0 d, $P<0.05$). Median travel time to Jones Beach for PIT-tagged spring/summer chinook detected at Bonneville Dam (inriver migrants) was significantly faster than for barge-released PIT-tagged spring/summer chinook detected during similar date ranges (median 1.5 d versus 2.0 d, $P<0.05$).

Unlike previous year's diel sampling efforts, there were no significant differences in day/night detection rates for juvenile chinook salmon in 1998 ($P=0.48$); peak detection periods occurred during early morning hours and at dusk.

We periodically assessed descaling rates of fish that passed through the PIT trawl. Based on our sampling, descaling averaged 17% (n = 580 fish). To minimize collection time, the fish sampled to assess descaling were captured when the trawl was collapsed and under tow at higher than normal velocity. As a result, we believe that these samples were

biased in favor of weaker or possibly previously impinged fish and overestimated descaling rates. To limit the effects of the trawl on fish, a camera continuously (and divers periodically) observed the trawl while deployed. Debris was cleaned from the detector and cod-end of the net whenever it was identified. When debris accumulation was severe, the detector was detached and the trawl inverted for cleaning.

EVALUATION OF MIGRATION AND SURVIVAL OF JUVENILE SALMONIDS FOLLOWING TRANSPORTATION

MPE-W-97-4

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The condition of juvenile salmonid migrants is affected by the structures and management procedures they encounter during migration; these effects influence the subsequent survival of the fish. This research is intended to provide information that will clarify the relationship between fish quality, as affected by structures and management, and migration behavior. With this information, it becomes possible to manage the migration of juvenile salmonids through the Columbia Basin hydropower system in such a way that later survival of migrants is maximized. Our goal is to make recommendations concerning how the fish transportation program may be managed to minimize the loss of fish in the Columbia River estuary.

Radiotelemetry (land-based fixed monitoring, boat tracking, and plane spotting) was used to monitor the migration and survival in the Columbia River estuary of yearling spring chinook that were barged from Lower Granite Dam or released (run-of-the-river: ROR) from Bonneville Dam. Pressure-sensitive radiotags, in addition to normal radiotags, were used to document the depth at which yearling chinook salmon migrate in relation to water salinity, which may influence the vulnerability of migrants to some species of birds. Also, a simulation of further transportation (and therefore stress) to the estuary of barged fish was carried out to compare performance of fish under different release strategies. Indices of stress, smoltification, and disease were measured pre- and post-migration (barged and ROR) in yearling spring chinook for comparison to survival and migration behavior of radiotagged fish released on the same dates. The relationship between degree of smoltification and salinity preference/survival of juvenile chinook salmon was determined in the laboratory for barged and ROR fish on several dates during the outmigration. These data will be compared to behavior of radiotagged fish that traveled through the estuary and into saltwater to determine if developmental stage at the time the fish reach the estuary (a function of barging) affects survival, such that incompletely “smolted” fish will delay entering saltwater and thereby be more vulnerable to predators in the estuary.

Findings indicate that pre-barged yearling spring chinook collected at Lower Granite Dam were generally more stressed through time than either post-barged or ROR fish, which were at similar stress levels when collected. Mean cortisol levels (our measure for stress) ranged from 43-159 ng/ml for all fish throughout the season, which is consistent with previous years' findings. Both gill (to be measured for ATPase, an indicator of smoltification) and kidney (to be measured for BKD) samples are currently being analyzed. Our saltwater preference and survival laboratory work indicated that preference for saltwater was greater as the season progressed and for ROR fish, although types of fish (barged or ROR) were never paired at one time due to fish availability. No mortality over 24 h occurred when fish were forced to enter saltwater.

A total of 334 yearling spring chinook were radiotagged and released below Bonneville Dam. Fourteen additional fish were tagged and released in the estuary for the enhanced stress/transportation simulation. Of all fish released, we were able to account for 70-100% of them downriver from Bonneville Dam for each of our releases (10 releases; N=20-50/release). Travel time to a fixed land-based monitoring station 90 miles downstream from the release site ranged from 24-118 h (with only 4 fish >70 h); this translates into a 0.7-3.7 mph swim speed. Travel time decreased as the season progressed (and dam discharge increased), with ROR fish traveling faster than barged fish on all dates. Based on data from radiotelemetry equipped boats, plane, and fixed electronic datalogging stations, mortality due to avian predators ranged from 5-30%/release (mean=17%). Trends indicate, though these data have not been analyzed, that ROR fish may have suffered greater avian-based mortality. This result is inconsistent with previous years' data.

We have made significant strides in GIS mapping of GPS data taken in boats while tracking individual fish. These georeferenced spatial data allow us to understand and visualize the fine-scale movement patterns of the outmigrating radiotagged yearling spring chinook in relation to specific geographical features, salinity, and tides. Salinity measures for 1998 indicate that saltwater intrusion did not extend upriver past the Astoria Bridge (river mile 13) and that salinity increased with depth, if at all. Depth tag data indicates that fish stayed in the upper 4 m of the water column, which is the least saline and most susceptible to avian predation. Large-scale migration patterns through the estuary, as seen in boats and corroborated with plane sightings, indicate that fish travel very close to the North channel and the main shipping channel. Many also use a specific, shallower route between the two channels (from main to North) in the area near the Astoria Bridge, which is a more direct path to the ocean. Upon reaching the estuary (arbitrarily demarcated at the top of Rice Island), fish generally require two or three tidal cycles to reach saltwater. Preliminary results indicate that fish movement in the estuary is strongly influenced by tides, with no fish holding in the estuary to resist entry into saltwater. A notable exception to this were the two fish tracked for the enhanced stress/transportation simulation. Both of these fish were spotted in the estuary after they should have been carried out to sea. These sightings were not on the two major bird colonies in the estuary, but mortality due to predation cannot be ruled out for these fish.

Results from 1998 are consistent with prior data with regards to stress, travel time and swim speed, avian mortality percentages, and migration routes and behavior. We gained insight into the issue of salinity and migration depth of yearling spring chinook. These data indicated that the fish do travel near the surface, possibly to avoid saltwater, where they are more susceptible to avian predators. Laboratory work also indicates that "more-smolted" fish prefer saltwater. However, all data have not been analyzed to their fullest extent at this time and further research to fill knowledge gaps needs to be performed. Given these promising gains in knowledge about saltwater entry, along with possibly higher mortality of ROR fish due to avian predation, we have made advances toward the increasingly important objective of formulating specific management recommendations for barge transportation of outmigrating yearling spring chinook.

CASPIAN TERN PREDATION ON JUVENILE SALMONIDS IN THE COLUMBIA RIVER ESTUARY (CTPS-98-1)

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The magnitude of Caspian tern predation on juvenile salmonids in the Columbia River estuary has recently become cause for concern. Our estimates of the number of smolts consumed in 1997 by the Caspian tern colony on Rice Island, a dredge material disposal island in the estuary, ranged from 6 to 25 million. Our objectives in 1998, the second year of our study, were to (1) estimate the size of the Caspian tern colony on Rice Island and determine population trend, (2) estimate the number of juvenile salmonids eaten by Rice Island Caspian terns, (3) identify and evaluate various factors that influence predation rates on smolts by Caspian terns, and (4) test the feasibility of potential methods to reduce predation on smolts by Caspian terns.

Photo census of Rice Island Caspian terns in 1998 indicated that this colony exceeds 10,000 nesting pairs, a 25% increase over 1997. The Rice Island Caspian tern colony is the largest of its kind in North America and continues to grow. In 1998, the diet of Rice Island Caspian terns was similar to 1997 and consisted primarily of juvenile salmonids (ca. 80% of prey items), mostly steelhead, coho, and chinook smolts. Caspian tern nesting success was about 40% in 1998, considerably higher than in 1997 when only 5% of nesting attempts produced fledglings.

Preliminary estimates of the numbers of juvenile salmonids consumed by Rice Island Caspian terns during the 1998 breeding season are in the range of 8 to 30 million smolts, about 8% - 30% of the number of juvenile salmonids that pass through the estuary. Results from the 1998 field season suggest that moving the Caspian tern breeding colony from Rice Island to East Sand Island may be an effective method to mitigate losses of smolts to terns in the estuary. East Sand Island is about 13 miles downriver from Rice Island and close to the mouth of the Columbia River. A greater diversity of forage fishes are available to fish-eating birds in the vicinity of East Sand Island compared to Rice Island. In 1998, double-crested cormorants nesting on Rice Island consumed a much higher proportion of juvenile salmonids (ca. 55%) than cormorants nesting on East Sand Island (ca. 10%). Caspian terns in the estuary foraged mostly within five miles of the breeding colony at Rice Island, and 90% foraged within 13 miles of the colony. Attempts in 1998 to attract Caspian terns to nest at a new site in the estuary (Miller Sands) using decoys and an audio playback system were successful. Finally, Caspian terns formerly nested on East Sand Island in the mid-1980s, and still frequently roost on the island.

These research results suggest that translocating the Caspian tern colony from Rice Island to East Sand Island is a feasible short-term management option for reducing tern predation on juvenile salmonids. Longer term management may include attracting portions of the current Rice Island Caspian tern population to nest outside the Columbia River estuary. Management action focusing on tern predation in the estuary may be an effective and efficient component of a comprehensive plan to restore salmon to the Columbia River Basin.

EVALUATION OF PROCEDURES FOR COLLECTION, TRANSPORTATION, AND DOWNSTREAM PASSAGE OF OUTMIGRATING SALMONIDS

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This study was undertaken to provide information that can be used to improve facilities and procedures for collection and handling of migrating juvenile salmonids on the Snake and Columbia Rivers. In addition, knowledge of the cumulative effects of passage through multiple dams is important for assessment of the relative effectiveness of in-river migration versus transportation. Finally, improved knowledge of how hatchery and wild fish respond to handling is needed to insure that handling procedures are optimized to benefit listed wild stocks.

Two Snake River Basin stocks were used for physiological comparisons of wild and hatchery spring chinook. Hatchery fish were obtained from Lookingglass hatchery (Grande Ronde River Basin); wild fish were a protected stock from the Imnaha River. Both hatchery and wild fish were raised from eyed eggs at Oregon State University's Fish Performance and Genetics Laboratory, Corvallis, Oregon. In the first experiment (1997), the results indicated that there was no cumulative stress response to passage through multiple dams. Analysis of a second experiment is in progress. In addition, comparisons of the health, smoltification and responses to handling of the wild and hatchery fish are continuing. Similar data are being collected from wild fish sampled from the natural environment. These studies will allow comparison and analysis of the effects of developmental stage, rearing history and genetics on the physiology and viability of spring chinook salmon.

Although handling of juvenile chinook salmon at fish collection facilities at Snake River and Columbia River dams is intended to be non-lethal, it is not known whether the procedures used ultimately affect the health and survival of the fish. For this reason, field and laboratory studies were conducted to investigate the effects of handling on juvenile chinook salmon. Water samples taken from marking troughs and raceways during fish marking operations at Lower Granite Dam were analyzed for detection of Renibacterium salmoninarum by culture. Despite the use of a selective culture medium to inhibit the growth of organisms other than R. salmoninarum, counts of total bacteria in the marking troughs were high (>10,000 bacteria per mL) in samples taken near the peak of the spring/summer chinook salmon out-migration. Counts of total bacteria in the marking troughs were lower (>1,000 per mL) in samples taken after the peak of the out-migration, but were still about four to five times higher than the counts from fish holding raceways, indicating that bacteria were being concentrated in the marking troughs. Because the rapid growth of other organisms precluded detection of R. salmoninarum by culture, the quantitative membrane filtration-fluorescent antibody test (MF-FAT) is being used for additional screening of samples for enumeration of R. salmoninarum cells. Other potential fish pathogens may also be concentrated in the water of the marking troughs.

The presence of high numbers of bacteria in the troughs may present a hazard to fish during handling and marking procedures. Laboratory experiments have shown that R. salmoninarum can become established in sites of skin injury. Because even minor skin injury resulting from handling procedures may provide a portal of entry for fish pathogens and opportunistic bacteria, further studies are investigating the use of cell viability stains for rapid identification of skin injury sites by gross observation.

Other laboratory studies are examining the effects of single and multiple stressors (such as those encountered during collection and transportation or passage through multiple dams) on the initiation and progression of R. salmoninarum infections. The results of a previous experiment suggested that R. salmoninarum can contribute significantly to seawater mortality of juvenile chinook salmon, even among fish not exposed to a handling stressor after exposure to the bacterium. The 1998 experiments (ongoing) are investigating the effects of single and multiple handling stressors on the transmission of R. salmoninarum, and the effects of fish holding density on the transmission of the bacterium.

Migrating wild and hatchery spring/summer chinook salmon and steelhead were sampled from gatewells at Lower Granite Dam in 1998 for determination of a range of physiological and health indices. These data, which have not yet been fully analyzed, will serve to establish baseline values needed for a comprehensive, multi-year evaluation of physiological data collected in earlier years.

EVALUATION OF THE EFFECTS OF MULTIPLE DAM PASSAGE ON THE PHYSIOLOGICAL CONDITION OF MIGRATING JUVENILE SALMON

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At present, few field data are available regarding the cumulative physiological responses ofjuvenile salmonids to passage through multiple dams. This information isneeded to determine the effects of passage through the hydropower system onfish condition and viability, to supplement ongoing studiesundertaken to determine relative smolt-to-adult survival rates fortransported and inriver migrating fish, and to determine if differences inhatchery rearing practices affect post-release survival. In the spring of 1998, a study was initiated using PIT-tag "diversion-by-code" systemsat dams on the Snake and Columbia Rivers to identify and sample groups ofmigrating spring/summer chinook salmon released from three Snake Riverhatcheries. Juvenile chinook salmon reared at Dworshak, Rapid River,and McCall hatcheries were sampled at Lower Granite, Little Goose, JohnDay, and Bonneville dams. Prerelease samples were also taken at the threehatcheries.

Tissuesamples were taken for determination of gill Na^{+},K^{+} ATPase activity; plasma cortisol, glucose,protein, triglyceride, cholesterol, chloride, sodium, potassium, calcium,alanine aminotransferase, aspartate aminotransferase, lactatedehydrogenase, and creatine kinase concentrations; organ size andappearance; erythrocyte vitamin E content, the occurrence oferythrocytic inclusion body syndrome; and carcass and gut water, lipid,protein and ash concentrations. In total, over 6000 samples will beanalyzed; about one-third have been analyzed at this time.

Initial evaluation of the dataindicates that total lipid reserves, which were initially highest inDworshak fish and lowest in McCall fish, declined rapidly during downstreammigration, falling to about 45% of prerelease values at Little Goose damand changing little at downstream sampling points. Declining lipidreserves were accompanied by declining plasma triglyceride, cholesterol,and total protein concentrations. At Bonneville dam, the lipid reserves ofDworshak fish were extremely low (2.6% of dry carcass weight), andsomewhat higher for McCall (4%) and Rapid River fish (6.7%). Thesediffering lipid levels are of interest because some published literaturehas indicated that the ability to adapt to seawater may be compromised insmolts with low lipid reserves. Alkaline phosphatase levels, whichmay reflect the rate of food intake, declined in the lower river. Thelevels of tissue-damage enzymes did not differ between hatcheries or showan increasing or decreasing trend from Lower Granite to Bonneville dams, but were consistently elevated in fish sampled at Little GooseDam.

HOMING OF ADULT CHINOOK SALMON WITH PIT TAGS THAT WERE OUTFITTED WITH RADIO TRANSMITTERS AT LOWER GRANITE DAM, 1997 AND 1998

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Radio transmitters were used to monitor migrations of adult spring and summer chinook salmon that had PIT tags implanted when they were juveniles to determine if they homed to their stream of origin or if they strayed to other streams. In 1997 and 1998, adult chinook salmon with PIT tags that returned to Lower Granite Dam were interrogated, diverted into the trap, outfitted with radio transmitters if they originated from a site upstream from Lower Granite reservoir, and then monitored during their migrations upstream from the dam. Seventy-one fish were outfitted with transmitters in 1997 and 30 in 1998. In 1998, we did not put transmitters in salmon that originated from the major hatcheries in the Snake River basin and thus the sample was about one-third of what we originally planned for. In 1997, 17% of the adults tagged had been transported downriver as smolts and the remainder were in-river migrants. In 1998, 30% had been transported as smolts. Fifty-six percent of the adults tagged in both years originated from hatcheries (had adipose fin clips) and the remainder were naturally produced.

We were able to determine that 20% of those tagged in 1997, and 43% of those in 1998 migrated successfully to their stream of origin (origin based on PIT tag records). Mortality of salmon with transmitters was relatively high in 1997 (62%), and lower in 1998 (37%). The salmon that we classed as mortalities were fish we were relatively certain did not survive to enter their natal stream or another stream used for spawning. We classified four salmon as strays in 1997 (6% if all fish, 15% of survivors), and 8 in 1998 (26% of all fish and 42% of survivors). Some fish strayed into a stream used for spawning (Grande Ronde River for example) but then moved back into the Snake River and did not survive to resume their migration to their home stream. These fish were classed as mortalities rather than strays.

Of the 101 adult salmon tagged at Lower Granite Dam in the two years, 80 had been in-river migrants as smolts in 1995 and 1996, and 29% of the adults homed to their stream of origin. The remaining 21 adults had been transported as smolts, and 19% of those fish homed to their stream of origin. The remainder strayed or died prematurely.

Fifty-seven of the 101 salmon tagged were of hatchery origin and 19% of those fish homed successfully versus a homing rate of 36% for the 44 natural salmon.

STUDIES TO ESTABLISH BIOLOGICAL DESIGN CRITERIA FOR FISH PASSAGE FACILITIES: IMPROVED WET-SEPARATOR EFFICIENCY AND HIGH-VELOCITY FLUME DEVELOPMENT, 1998

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During the 1998 spring and summer juvenile salmonid outmigrations, research was carried out to provide refined biological design criteria for the improvement of wet separators currently in use at fish passage facilities at hydroelectric dams on the Snake and Columbia Rivers. Tests were also continued to develop the high-velocity flume wet separator concept for juvenile salmonid migrants.

Two evaluation separator units were used to trap river-run smolts from Gatewell 6B at McNary Dam. A new evaluation wet-separator unit was constructed with a footprint similar to the small fish section ('A' section) of operating separators, to simulate the geometry and function of an existing separator. Using this unit, six treatments compared the effects of separation-bar spacing and flow diverters on juvenile salmonid separation, orifice exit efficiency (OEE), and fish condition. Separation and OEE were also evaluated over twelve combinations of separation-bar spacing, separation-bar angle, and water velocity with a prototype high-velocity flume (HVF) separator.

Preliminary analysis of data for the spring outmigration revealed mean separation efficiency values ranged from 64 to 83% for all salmonids <180 mm, and from 69 to 92% for smolts 180 mm with the evaluation wet separator. Using the HVF separator, mean separation efficiency ranged from 29 to 83% for fish <180 mm, and from 63 to 100% for larger smolts.

More than 98% of the catch during the summer outmigration consisted of subyearling chinook salmon <180 mm. Subyearling chinook salmon separation efficiency ranged from 81 to 92% using the evaluation separator, and from 61 to 91% with the HVF separator.

IMPROVED WET SEPARATOR EFFICIENCY AND DEVELOPMENT OF METHODS FOR SECONDARY SEPARATION OF LARGE AND SMALL SMOLTS

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Juvenile salmonid bypass facilities at hydroelectric dams on the Snake and Columbia Rivers are used to collect juveniles for subsequent transport or release downriver. Because it is believed that juvenile chinook salmon that are confined or transported with juvenile steelhead (which are larger and more aggressive than chinook salmon smolts) experience higher levels of stress than those transported with other chinook salmon, separation of smolts by size has been an objective of juvenile bypass systems for a number of years. Fish separators, arrays of shallowly submerged, parallel plastic bars, are used to segregate smaller smolts such as chinook and sockeye salmon from steelhead smolts. The separators are also used to separator adult salmonids, nonsalmonid incidental species, and debris from the juvenile fish.

In practice, there are several problems with existing wet-separators: small and large fish are incompletely separated, and fish may delay for long periods both above and below the separator bars. Over the past several years, we have performed various on-site studies to determine how fish separator performance might be improved.

The first objective in 1998 was to determine the effectiveness of secondary in-flume separation of large and small smolts. The in-flume separators were constructed of horizontal 1 inch (O.D.) aluminum bars with 5/8 inch spacing placed 7_9 cm below the water surface, and were positioned near the downstream end of the flume leading from the separator to the east bank of raceways the Lower Granite Dam fish handling facility. Two designs were compared, one 2 meters and one 3.5 meters in length. Larger fish that could not pass through the bars were diverted into a raceway by a stop plate at the end of the device; smaller fish passing through the bars traveled on down the flume to another raceway. The performance of the two designs tested in 1998 did not differ significantly, but the results of the 1997 and 1998 tests taken together indicate that separation efficiency increased in proportion to separator length, and was about 80% with the longest design tested (3.5 meters). This simple, inexpensive device separates smaller and larger smolts well, but additional engineering studies are needed to solve the potential problem of debris accumulation.

The second objective in 1998 was to determine if separation of smaller and larger smolts by the fish separator at Little Goose Dam could be improved by increasing light intensities over the separator. An array of halogen lamps was installed above the upstream separator section and operated on a 48-h on/48-h off cycle for 52 days from 11 April to 1 June. The mean separation efficiency for yearling chinook salmon (percentage of fish passing through the upstream section) was 59% with the lights off and 69% with the lights on ($P < 0.01$). However, the percentage of hatchery and wild steelhead passing through the upstream section was also significantly increased, from 12% to 18% ($P = 0.02$) and from 37 to 41% ($P = 0.06$). The result was that the chinook salmon:steelhead ratio for both the upstream and downstream separator sections differed little between the two lighting conditions.

The third objective in 1998 was to determine if partial separation of smaller fish and larger fish could be achieved by providing a "sanctuary" area into which smaller fish would be attracted by a flow of water, while larger fish would be excluded by appropriately spaced bars. This concept was tested in the raceways used to hold "daily sample" fish at McNary Dam. Use of daily sample fish provided a known number of smolts of known species composition for each trial. The fish were confined to the downstream 3.3 m of a raceway by a blocking screen. After the raceway had been loaded, a bar screen with 13 mm spacing between bars was placed behind the crowding screen and the crowding screen removed. Flow entering from a diffuser plate on the bottom of the upstream end of the raceway provided attraction flow through the separator bar screen. Two flow rates were tested (25 and 100% of the maximum flow available), and 5 trials were completed by each flow rate. After overnight holding, the blocking screen was replaced, the water level lowered, and all fish upstream of the separator bars were lightly anesthetized and counted by hand to determine total number and species composition. Analysis of these data are incomplete at this time.

SPORT FISHING USE AND ANGLING CHARACTERISTICS ON THE LOWER SNAKE RIVER RESERVOIRS

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A creel survey of the sport fisheries in the four Lower Snake River reservoirs was conducted from April through November 1997 as part of the *Lower Snake River Feasibility Study*. We used a combination of aerial flights and in-person interviews at access points throughout the nearly 220 km (140 mile) reach to estimate angler effort, catch and harvest, catch and harvest rates, and various angler attributes. Interviewed anglers were also asked to participate in follow-up economic surveys that will be used to determine the monetary worth of the reservoir sport fishing.

We estimated a total of 111,461 angler trips produced 489,215 hours of angling effort on the four reservoirs. Lower Granite Reservoir received the most fishing effort (220,605 hours), followed by Ice Harbor Reservoir (106,281 hours), Lower Monumental Reservoir (92,520 hours), and Little Goose Reservoir (69,809). Little Goose Reservoir received the most use during the spring and summer, whereas Lower Granite Reservoir experienced the most use from September through November. Overall, more than 70% as much effort was expended by boat anglers (308,546 hours) as shore anglers (180,669 hours). Ice Harbor Reservoir supported the highest proportion of use by shore anglers (63,350 hours), whereas Lower Granite Reservoir received the highest boat angling effort (181,544 hours). Night angling occurred throughout the four reservoirs, although principally in Ice Harbor Reservoir in the summer months and Lower Granite Reservoir from mid-August through November. The large majority of anglers visiting the lower Snake River reservoirs was local and made mostly day fishing trips.

The most intensive angling effort in the Snake River reservoirs occurred during the September through November period when anglers targeted steelhead. Boat anglers expended more than 70% of the total effort during this time. Among the reservoirs, Lower Granite supported the bulk of boat angling effort, which was particularly focused at the Snake River-Clearwater River confluence area in Lewiston-Clarkston. Most shore angling for steelhead occurred at fishway exits or entrances in Ice Harbor and Lower Monumental reservoirs.

Reservoir anglers caught an estimated 140,358 fish and harvested 59.2% (83,066). Seasonally, catch and harvest were highest in July and lowest in October and November. The highest catch occurred in Lower Granite Reservoir (41,941 fish), whereas the highest harvest occurred in Ice Harbor Reservoir (29,128 fish). The estimated yield of sport fish in the lower Snake River reservoirs overall ranged from 7.60 kg/ha in Lower Granite Reservoir to 2.05 kg/ha in Little Goose Reservoir.

Steelhead was the most frequently sought species throughout the lower Snake River reservoirs during 1997. Other species pursued by Lower Snake River reservoir anglers were channel catfish, smallmouth bass, and stocked rainbow trout. Stocked rainbow trout *Oncorhynchus myksis* provided a substantial April-early June sport fishery (anglers caught 15,770 trout) in mitigation ponds along the reservoir corridor. Channel catfish *Ictalurus punctatus*, crappie *Pomoxis spp*., and smallmouth bass *Micropterus dolomieui* largely supported the sport fishery in the main portion of the reservoirs in late spring and summer. Crappie were the most abundant sport fish caught (34,072) and harvested (22,313) from the reservoirs in 1997. During August through November, we estimated 13,147 steelhead were caught and 9,541 harvested in the Lower Snake River reservoirs. Most of the catch (8,429) and harvest (5,390) occurred in Lower Granite Reservoir, principally by boat anglers. In contrast, the bulk of the steelhead catch and harvest in Lower Monumental and Ice Harbor reservoirs was by shore anglers.

USE AND ANGLING CHARACTERISTICS OF THE SPORT FISHERY ON THE SNAKE RIVER , UPSTREAM OF ASOTIN, WASHINGTON

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A creel survey of the sport fishery in the 48 km (30 mile) free flowing reach of the Snake River immediately upstream of Asotin, Washington was initiated in September 1997 and continued through March 1998 as part of the Lower Snake River Feasibility Study. The survey was designed to provide data that could be used to estimate potential angling use of the 220 km (137 mile) impounded section of the lower Snake River if restoration to a free flowing system were the selected alternative. A combination of aerial flights, in-person ground interviews at several access points along the river, and follow-up phone interviews were used to estimate angler effort, catch and harvest, catch and harvest rates, and various angler attributes. Interviewed anglers were also asked to participate in a follow up economic survey to estimate the monetary worth of the sport fishery in this reach.

A total of 16,120 angler trips produced an estimated 88,940 hours of fishing effort on the free flowing reach, upstream of Asotin. Monthly effort peaked during November (39,909 hours) and declined substantially after December. Overall, more than 83% as much effort was expended by boat anglers (74,281 hours) compared to shore anglers (14,658 hours). Boat angler use peaked in November, whereas shore angler use was highest in October. Among the anglers interviewed 93% sought steelhead.

From September through March, anglers caught an estimated 20,592 fish and kept 58.4% (12,026 fish). The highest catch occurred in November (7,239 fish), and the lowest was in March (92 fish). October (4,372 fish) and November (4,322 fish) represented the peak harvest months. Steelhead *Oncorhynchus mykiss* were the predominant sport fish taken from October through February, and overall comprised 68.5% of the total catch and 74.3% of the harvest. The principal resident species caught and harvested (C/H) were northern pikeminnow *Ptychocheilus oregonensis* (3,230/2,527) and smallmouth bass *Micropterus dolomieu* (1,537/477). The total yield of the sport fishery in this reach from September through March was 30.04 kg/ha, of which 94.8% (28.47 kg/ha) was steelhead.

The overall directed catch and harvest rates for those anglers specifically seeking steelhead averaged 0.153 and 0.093 fish/hour, respectively. Directed catch rates for steelhead were highest in October (0.170 fish/hour) and November (0.173 fish/hour) and generally similar between boat (0.199 fish/hour) and shore anglers (0.188 fish/hour).

The 48 km reach of the Snake River upstream of Asotin was fished primarily by local anglers (Lewiston, Clarkston, Asotin) on day fishing trips although during peak angling months of October and November, anglers from outside the region outnumbered local anglers. Our results indicated the fall-winter sport fishery along the 48 km reach of the Snake River upstream of Asotin, Washington was clearly dominated by anglers pursuing steelhead. Although we found monthly variability in the distribution of effort between shore and boat anglers and among species sought, the fishery during October through February was virtually for steelhead.

PREDICTING THE EFFECTS OF RESERVOIR DRAWDOWN ON JUVENILE SALMONIDS AND THEIR PREDATORS

(Project Number: DDS-W-98-4)

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One hypothesized benefit of reservoir drawdown or dam breaching is a reduction in the number of juvenile salmonids consumed by predators in the managed reach. Under this hypothesis, reservoir drawdown should increase the average migration rate of juvenile salmonids and reduce the time migrants are exposed to predators, thus reducing predation loss. Predation by northern pikeminnow *Ptychocheilus oregonensis* and smallmouth bass *Micropterus dolomieui* is believed to be the main source of mortality for juvenile salmonids in reservoirs, causing as much, or more, mortality per reservoir as dam passage. Predicting the direct and indirect consequences of drawdowns on predation, however, depends on some critical assumptions about the behavior of predators and prey in reservoirs and free-flowing river reaches.

The goal of this study is to provide data, analyses, and tools to better evaluate and monitor the effects of lower Snake River drawdown on predation-related juvenile salmonid mortality. We will emphasize the spatial variation in habitat under different operational conditions and how this variation may cause changes in predator and prey distributions, predator diets, predator population size and structure, and ultimately juvenile salmonid mortality. Our general approach is to describe and model predation dynamics in free-flowing reaches of the Snake and Columbia rivers, assuming that drawdown or dam breaching will create riverine conditions. The project began in 1998, so results are preliminary. Results from the Snake River study reach will be emphasized in this review.

During 1998, northern pikeminnow and smallmouth bass were studied within the free-flowing lower Snake River and the Hanford Reach of the Columbia River to characterize food habits, habitat selection, population structure, and age-0 growth and mortality. Existing data on habitat use by fall chinook salmon and smallmouth bass are being collected from collaborators and the literature.

We used a stratified random design for sampling habitat use and densities of smallmouth bass and northern pikeminnow. On the Snake River, the plan was implemented from Asotin (WA) upriver to a site about 3 miles above Rogersburg, near the confluence with the Grand Ronde River (about 25 river miles). This reach is similar in gradient and other characteristics to the Snake River reservoirs between Ice Harbor Dam and Lower Granite Dam. On the Hanford Reach, we sampled from Ringold upriver to Coyote Rapid (about 23 river miles). In each area, we classified the study reach into macrohabitat zones (pools, runs, islands) and “units” within a macrohabitat zone that had consistent nearshore substrate (sand, cobble, boulder, etc.). Boat electroshocking was used to collect data on over 250 substrate units in the Snake River area and over 200 substrate units in the Hanford Reach. Gut samples were taken on all predators collected (*N* = 1,266; fish ≥200 mm FL) to provide diet information. Predator densities will be estimated for different river reaches, macrohabitats, and substrate types (sand, cobble, etc.). Preliminary estimates suggest that the biomass of predators in the Snake River study area may be >80% greater than the biomass in the Hanford Reach study area.

During July-September, larval and juvenile predators were sampled by weekly beach seining from nearshore areas of the Hanford Reach. A total of 123 samples were collected, from which age-0 growth and mortality will be estimated.

Individual adult predators were radio-tagged within the same river reaches as described above. Fifty-seven fish (29 northern pikeminnow and 28 smallmouth bass) were radio-tagged in the lower Snake River, and 45 fish (25 northern pikeminnow and 20 smallmouth bass) were tagged in the Hanford Reach. We detected at least once 55 of 57 tagged fish in the Snake River through either boat tracking or by a fixed station located at the Anatone gauge. Forty-one of 45 fish were detected at least once in the Hanford Reach. After detection, location-specific habitat data were collected on substrate, water depth, water velocity, distance to shore, and vegetation. A set of random locations was also sampled to describe the available habitat in the rivers.

Preliminary data summaries suggest that radio-tagged predators showed preferences for areas that were shallow, nearshore, in low-velocity or turbulent water, and with boulder or bedrock substrates. Some tagged fish moved several miles up the Snake River into the Grand Ronde River, possibly for spawning, and their rate of movement appeared high. Several of these fish moved back down to their original capture location. There may be an especially large number of predators migrating into Chief Joseph Creek, a small tributary of the Grand Ronde River. No tagged predators were observed moving downriver into Lower Granite Reservoir.

Predation results will be synthesized by modeling studies. Resource selection models will be developed that describe the relative habitat use by predators. Changes in predator and prey habitat will be described in a spatially-explicit framework by using pre-impoundment (1934) maps and simulation results from other regional researchers. Bioenergetics modeling will be used to estimate the potential change in the number of salmonids consumed during a drawdown or river normalization.

IMPORTANCE OF SPAWNING HABITAT IN THE TAILRACES DOWNSTREAM OF LOWER SNAKE RIVER DAMS TO FALL CHINOOK SALMON

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We conducted studies from 1993-1997 to search for and to characterize fall chinook salmon spawning sites in areas immediately downstream of the four lower Snake River dams. Specific study objectives were to 1) determine if fall chinook salmon spawned in the tailrace or other locations where construction activities or dam operations could adversely impact their reproductive success, (2) document the distribution and abundance of redds, and 3) obtain detailed information on spawning habitat. Initial efforts to locate spawning areas using aerial surveys with fixed-wing aircraft and reviewing data from adult radiotracking studies were unsuccessful. We subsequently applied Geographic Information System (GIS) technology to create maps of potential spawning habitat (primary search areas) at each of the four lower Snake River dams. A boat-deployed underwater video system was then used to survey for salmon redds. The camera's position was tracked using a Global Positioning System (DGPS) system and linked to a field PC equipped with GPS visualization software.

We located fall chinook salmon redds downstream of three of the four lower Snake River projects during four survey years. Frequency of use was variable among sites, but site fidelity was high. Lower Granite Dam had the highest redd total (14 redds in 1993), but Little Goose Dam had the highest frequency of use (all 4 years). At both dams, redds were located on the powerhouse side of the tailrace and downstream of a high volume discharge emanating from the original juvenile bypass outfall. Only one redd was found at Ice Harbor Dam in 1996. No evidence of spawning was observed downstream of Lower Monumental Dam.

Operation of existing hydroelectric facilities in the lower Snake River has created physical habitat conditions suitable for spawning by fall chinook salmon. These conditions appear to exist for only short distances downstream of most projects. Thus, any modification to the channel, including dredging, addition of instream structures (e.g., bypass outfalls), and changes to project operations (e.g., reservoir drawdown, spilling) that may affect preferred substrate and hydraulic conditions beneficial to spawning need to be carefully evaluated to ensure that potential impacts to fall chinook salmon are minimized. Similarly, it may be possible to enhance use of tailrace areas by manipulating reservoir pool elevations and altering project discharge. Collectively, our studies demonstrate that future recovery planning for listed fall chinook salmon needs to consider the importance of these lotic habitats to remaining mainstem and tributary populations.

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ASSESSMENT OF SALMONID HABITAT FROM A GEOMORPHIC PERSPECTIVE:
LOWER SNAKE RIVER, WASHINGTON

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The response of lower Snake River salmonids to drawdown has been assessed using salmon passage models and life-cycle models. However, the type of modeling needed to assess geomorphologic changes resulting from drawdown, and the effects of those changes on salmonids, has not been conducted for the lower Snake River. The objective of our study is to assess the interaction between geomorphologic changes and salmonid habitat requirements. The conceptual framework for this study is based on assessing the cause/effect/result relationships that exist between the attributes of alluvial rivers and the controlling factors that create them. Efforts to date have focused on developing the necessary GIS data layers. Recent work has addressed three controlling factors: channel substrate, channel morphology, and sediment transport. GIS modeling of pre-dam hydrologic regimes indicates that fine sediments accumulated following dam construction will be eroded and transported out of the lower Snake River reservoirs within five years.

REVIEW, ANALYSIS, INTEGRATION, AND SYNTHESIS OF EXISTING AND FUTURE PIT-TAG DATA RELEVANT TO SNAKE RIVER ANADROMOUS SALMONID STOCKS

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Hundreds of thousands of Snake River juvenile salmonids, of both wild and hatchery origin, have been PIT-tagged and released over the past decade for various specific research purposes. Additionally, substantial numbers of adult returns from these releases are beginning to occur. PIT-tagged Snake River salmonids have been transported, bypassed (intentionally or accidentally), spilled, passed through turbines, sluiceways, and a prototype surface collector. Fish of known size and condition have been PIT-tagged and/or released from natal streams, at hatcheries, dams, traps, from barges and trucks; the fish have outmigrated under varying flow volume and water quality conditions and during different times of the year. PIT-tagged fish have been detected after release (as juveniles) at traps and dams, in seines, and other capture gear. Adults have been detected in fisheries, at dams, and at hatcheries. In short, a huge amount of information is available on PIT-tagged fish.

All of the tagging and detection data from these fish are housed in the PTAGIS data base, and researchers are analyzing PIT-tag information from their particular studies. It seems likely, however, that useful information that is not specifically related to the objectives of a particular study might be missed. The first part of this study was the identification of specific issues and the evaluation of feasibility for further study. The areas selected for initial evaluation include:

1. **Evaluating the differences in outmigration dynamics exhibited by wild versus hatchery stocks of chinook, steelhead, and sockeye.**

An issue that can be addressed with PIT-tag data is the relative performance of wild versus hatchery fish. Since many of the wild fish are protected under the Endangered Species Act, their availability for research purposes is becoming more limited. A remedy for this problem is to use hatchery fish in research studies. A pertinent question is whether hatchery fish are reasonable surrogates for wild fish. Methods for addressing this question in terms of migratory dynamics were investigated. Numerous studies have related variability in juvenile salmonid travel times to river flow and a variety of other factors. Also the survival of fall chinook has been related to date, temperature, and river flow. Clearly, observed migratory dynamics is related to river conditions. Because of this, all comparisons will rely on a paired release design where groups of hatchery and wild fish are released during the same period at the same site. The first step is to identify possible release groups that fit these criteria, and make comparisons using a number of approaches.

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One method involves comparing travel time distributions of hatchery and wild fish through a single reach looking for consistent differences in migration rate and population spread between the two types of fish. The second method involves performing parallel regression analyses on hatchery and wild stocks to reveal whether the two types of fish respond differently to environmental covariates. The third method is to compare the behavior of release groups of hatchery and wild fish as they migrate through multiple reaches. Zabel et al. (1998) present methods for assessing qualitative behavior of cohorts as they migrate through multiple reaches. By comparing alternative migration models to data, the migratory behavior of hatchery and wild fish can be determined as it evolves through the season and as fish migrate downstream. In addition, other measures can also be examined, such as fish guidance efficiency, that may reflect a difference in guidance behavior between wild and hatchery stocks.

2. Partitioning reach survival estimates from PIT-tag studies into components associated with reservoir and project mortality.

Most of the studies on the detrimental effects of dams on juvenile salmonid survival performed in 1993-97 have targeted Lower Granite Dam, as this dam is the most upstream of the Lower Snake River dams, and consequently, it passes the highest numbers of Snake River drainage smolts listed under the Endangered Species Act. A simple model that partitions overall reach survival into two components corresponding to the reservoir and dam survivals was explored, along with a comparison of results to the balloon tag, radiotelemetry, and hydroacoustic studies performed at Lower Granite Dam in 1993-97 and their corresponding survival and/or survival-component estimates.

3. Relating smolt survival to data on smolt condition indices.

Smolt condition during outmigration in the Columbia River Basin has been the subject of a number of analyses performed before, but with the goal of comparing these factors to smolt travel times. Information on smolt condition during out-migration has been collected sporadically for a number of years, but improvement in tagging technology and data collection has increased the amount of information available on the physiology of the smolt, not only at the time of tagging, but also at a recapture event further down the river. This data, though often too few in number to be of use within a specific study, may be enough when pooled to make general observations in regards to a species, an outmigration run or release site. The major indication of condition at the time of tagging is the size of the fish. A secondary measure of condition is weight and a third is the rate of growth, which can be determined by the weight or length difference between tagging and recapture. In this preliminary analysis, we considered the length at the time of tagging.

4. Estimate survival rate in nonimpounded segments of the Snake River for comparison with impounded reaches.

Most of the reach survival estimates surveyed reflect the combined smolt survival through free-flowing waters and the Lower Granite impoundment and dam. In a few cases, investigators have attempted to isolate the free-flowing survival component. In other instances, the reach survival estimates also reflect overwinter survival during the parr stage for wild fish tagged in-river the preceding summer. We considered all these types of estimates in the survey, and make recommendations as to the utility of these different classes of reach survival estimates for making free-flowing survival estimates.

SNAKE RIVER DRAWDOWN MODELING IN CRiSP

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This talk outlines an approach to investigate the impacts of drawdown on smolt survival. It uses a mathematical analysis, CRiSP survival results, and information from the Lower Granite Reservoir drawdown study in 1992 to estimate a potential range of survival under a range of predator behavior and environmental assumptions.

From a mechanistic perspective, drawdown will alter the environment in several ways that can be counteracting. Drawdown increases the velocity of the water and so it decreases the travel time of fish through the Snake River. This decreases the exposure to predators and can contribute to increasing survival under drawdown as compared to the full pool survival. A compensating impact occurs because the predators are concentrated into a smaller area with drawdown which increases the exposure of smolts to predators. This factor can decrease survival in drawdown. In addition, the increased velocity with drawdown increases sediment transport and water turbidity, which decreases the visual foraging area of predators. This factor can increase survival. These three processes are interactive so it is not intuitively clear how drawdown will change smolt survival. The empirical and mechanistic model formally expresses the interactions in terms of three parameters: fish velocity as a function of water velocity, a turbidity changes with drawdown and the predator depth distribution with drawdown.

For spring chinook migration the model predicts that the survival through the lower Snake River with drawdown would be between 0.59 and 0.85. For a comparison, the observed and CRiSP predicted survival over the lower Snake River reach for 1998 was about 0.7   Thus, the Snake River survival could decrease or increase by about 15% with drawdown.